

THE BIOLOGICAL, CHEMICAL, AND PHYSICAL CHARACTER OF LAKE MICHIGAN
IN THE VICINITY OF THE DONALD C. COOK NUCLEAR PLANT

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INTRODUCTION

This report is a compilation of papers on the environment in southeastern Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant. The papers cover the biological aspects studied as well as some of the physical characteristics of the lake in this area.

The data used in this report have been gathered by staff members of the Great Lakes Research Division of the University of Michigan involved with the Cook Plant environmental monitoring project over the past years. The initial field investigations were begun in 1966, and the scope of the project increased until in 1973, 33 different field trips were made with a total duration of 105 days. These field operations ranged from 1 to 8 days in duration and involved field crews ranging in number from 1 to 10 scientists. Table 1 summarizes the 1973 field operation activities.

In addition to the regular preoperational field surveys, preliminary entrainment studies of plankton, fish larvae, and impinged fish commenced in January 1973. This preliminary work was undertaken to collect data which could aid in making the decisions as to equipment requirements and method adequacy, prior to the plant going on line.

The study to date and this report required the efforts of many devoted personnel. We appreciate the tireless efforts of our research group, including M. Butler, C. Garcia, B. E. Hawkins, B. Higgins, L. C. Igras, E. M. Johnston, S. Kleinschmidt, S. Malosh, M. Omair, H. K. Soo, M. Wiley, S. B. Williams, M. Winnel, C. M. Zawacki and T. W. Zdeba, for their assistance in gathering, analysis and compilation of the data presented here. The typing of the manuscript by J. Farris, H. E. Ayers and J. Handyside cannot go unacknowledged. For assistance in editing the manuscript we thank M. N. Everett. To the Cook

TABLE 1. Summary of the 1973 field operations. The trips are listed in chronological order along with the duration, crew size, and categories of work done during the trip. The field work listed under other in the table includes sediment and sediment geochemistry sampling, sampling equipment experiments, shorebird feeding habits as well as transfer, installation, maintenance and testing of equipment.

	# of # of	Beach	Gill	Fish	Benthos	Plankton	Benthos & Inshore	Inshore Peri-	Phyton	Psammon	Diving	Ice	Ent.	Other
	days	people	netting	trawling	larvae	seasonal	seasonal	plankton	benthos	phyto.				
Jan. 3	1	2												
Jan. 10-12	3	4												
Jan. 19-20	2	3												
Jan. 30-Feb. 2	4	4												
Jan. 14-15	2	5												
Feb. 14-15	2	5												
Feb. 21-23	3	5												
Feb. 27	1	3												
Mar. 14-18	5	6												
Mar. 26-28	3	2												
Apr. 3-5	3	9												
Apr. 12-14	3	5												
Apr. 18-20	3	3												
Apr. 23-27	5	8												
May 15-19	4	2												
May 29-31	3	4												
Jun. 8-10	3	1												
Jun. 17-21	5	10												
Jul. 3-5	3	5												
Jul. 16-21	5	10												
Aug. 8-10	3	4												
Aug. 15-16	2	7												
Aug. 17-24	8	2												
Aug. 30-31	2	2												
Sept. 5-7	3	4												
Sept. 13	1	1												
Sept. 17-22	6	8												
Oct. 10-11	2	5												
Oct. 22-26	6	9												
Nov. 2	1	2												
Nov. 12-15	5	9												
Nov. 20-21	2	2												
Dec. 17-18	2	3												
Dec. 26-28	1	1												
Shore														
Onboard														
WMSIS														
FAITH II														
DOC														

Plant Construction and Operations staffs who assisted us in our field efforts, we are particularly thankful. The skill and patience of the captain and mate of the R/V MYSIS, F. Dunster and E. Wilson, must be acknowledged.

PREOPERATIONAL DISTRIBUTION OF BENTHIC MACROINVERTEBRATES
IN LAKE MICHIGAN NEAR THE COOK NUCLEAR POWER PLANT

Samuel C. Mozley

Abstract. A preoperational, multiseasonal study of zoobenthos near the Cook Nuclear Power Plant was initiated in July 1970 with the goal of determining the time-and-space-averaged effects of plant discharges on the ecology of nearshore Lake Michigan. The present report covers data from 1972 and 1973 field studies. The plant has not yet begun to generate electricity.

Benthic macroinvertebrates in the nearshore areas of southeastern Lake Michigan are diverse and abundant, particularly lakeward of the 8 m depth contour, and numbers per unit area increase with increasing depth. Several species are characteristic of shallow, intermediate or deeper parts of the survey area. Some common species, especially *Pontoporeia* and Chironomidae larvae, show regular seasonal fluctuations. Chironomidae, Naididae, Hydracarina and *Pontoporeia* occur above bottom near shore, where they will be subject to entrainment into the power plant. Their occurrence appears to be seasonally restricted, however, to midsummer nights, and possibly to midwinter (for *Mysis* and breeding *Pontoporeia*).

Statistical ability to detect differences between mean total animals at two locations, or on two dates at one location, extends to differences no smaller than several thousands per m^2 between 0 and 8 m depths and 20,000/ m^2 between 8 and 40 m depths. Year-to-year changes in the zoobenthos exemplified by early release of young *Pontoporeia* in 1973, appearance of large numbers of Naididae in 1973, and steady year-to-year increases in numbers of Tubificidae will make differences due to plant effects very difficult to detect. Broad variability also occurs in small areas on one date, leading to the aforementioned low statistical sensitivity. Only massive changes in zoobenthos near

the plant would be conclusively interpretable as due to plant effects.

The condition of the benthic environment, judging from the composition and abundance of species assemblages, is moderately enriched and probably becoming more and more favorable to the deposit-feeding worms.

INTRODUCTION

ORIGIN OF THE COOK ZOOBENTHOS STUDY

Under provisions of federal and state laws, each new electric power generating plant on the shores of the Great Lakes must show the environmental damage which may be done as a result of operation, before it can be licensed to discharge waste heat and materials. In addition, an environmental survey must be conducted through the first years after operation begins to determine whether any changes in the nearby environment or biota result from discharges. To support the evaluation of probable impact, and to fulfill part of the requirements for ecological surveys, the University of Michigan has been studying the aquatic plants and animals in southeastern Lake Michigan near the Donald C. Cook plant since 1967. A regular seasonal survey of benthic macroinvertebrates has been a part of those studies since July 1970. The benthic surveys, more than any other segment of the study, are intended to demonstrate any time-averaged spatial effects of discharges on processes which control the benthic environment, such as heating of the near-bottom water and sedimentation, through changes in numbers or kinds of bottom-living animals.

REVIEW OF OTHER BENTHIC STUDIES IN SOUTHERN LAKE MICHIGAN

When benthic surveys were begun, very little information was available on the kinds, numbers and spatial and seasonal abundance patterns of macro-

invertebrates in bottoms near shore anywhere in Lake Michigan. Shelford (1913) outlined the qualitative characteristics of benthic depth zonation, mainly as a function of light and sedimentary conditions. The shallowest zone was defined by the depth to which waves moved sand, about 8 m. This band around the lake was said to be very heterogeneous due to the variety of substrates in it. "Eroding" bottoms of exposed bedrock, cobbles or boulders were inhabited mainly by large insect nymphs and *Hyaella*. "Depositing" bottoms of shifting sand supported few or no animals out to 4 m; between 4 and 8 m the bottom was inhabited by *Sphaerium striatinum*, a few midge larvae (Chironomidae), and a snail, *Lymnaea*. The zone between depths of 8 and 25 m was delimited at the lower edge by the depth to which broad thermal fluctuations were believed to occur. The most abundant taxa were said to be *Crangonyx*, *Sphaerium*, *Amnicola*, *Valvata* and *Lymnaea*, plus oligochaetes, chironomids and leeches in the southern tip of the lake. The third zone (25-64 m) was defined by thermal fluctuations of 3°C or less, and was believed to be the shallowest zone in which *Pontoporeia* and *Mysis* were common. The deeper limit was presumed to be controlled in some way by light penetration.

Knowledge of present-day southern Lake Michigan benthic macroinvertebrates, outside of newly established monitoring programs at several power plants, is largely at higher taxonomic levels. The numerically dominant taxon is Amphipoda, followed by Oligochaeta, Sphaeriidae and Chironomidae in that order (Powers and Alley 1967; Robertson and Alley 1966). Near shore Gastropoda, Hirudinea, other Insecta and occasionally other Crustacea may be numerous. Total animals increase in number to depths of 30-50 m where they reach a maximum. Numbers then decrease with increasing depth. The relatively large opossum shrimp, *Mysis relicta*, is benthic during the daytime at depths to about 90 m but becomes planktonic at greater depths and at night (Powers

and Robertson 1965). It is usually rare near shore.

The Amphipoda are almost entirely composed of the glacial relict species, *Pontoporeia affinis*. *Pontoporeia* follows the depth distribution pattern of total animals with maximum abundance at depths of 30-50 m (Alley 1968). At depths less than 20 m, *Pontoporeia* matures in one year but requires two or more years at greater depths. Breeding occurs during the winter, and young are carried into spring in brood pouches of the females. Young are released at a size just under 2 mm long in late spring (Alley 1968).

At depths less than 30 m, the second most abundant taxon is usually the Tubificidae (Oligochaeta). These are composed of several species, especially *Limnodrilus hoffmeisteri*, *Potamothenis moldaviensis*, *Pelosciolex freyi*, *P. ferox*, and *Tubifex tubifex*, with variable but usually small proportions of a variety of other *Limnodrilus*, *Aulodrilus*, *Pelosciolex* and *Potamothenis* species (Hiltunen 1967). The seasonal changes in numbers of Tubificidae species are not pronounced, but there appear to be larger population sizes in summer than in spring or fall (Hiltunen 1967).

The lumbriculid oligochaete, *Stylodrilus heringianus*, is abundant at depths over 20 m (Hiltunen 1967; Mozley and Garcia 1972) and Naididae contributed a small proportion inshore (Hiltunen 1967). Very near shore the Chironomidae make up most of the total animals (Truchan 1970; Mozley and Garcia 1972). They are also diverse, with important fractions in the genus *Chironomus* and other Chironomini and Tanytarsini.

The Sphaeriidae are composed of two genera, *Sphaerium* and *Pisidium*. The former is represented mainly by three species, *S. nitidum*, *S. striatinum* and *S. corneum*. The *Pisidium* include at least 9 species, but the deep water form *P. conventus* is easily the most abundant. *P. casertanum*, *P. henslowianum* and *P. lilljeborgi* are important species of this genus in shallower water

(Robertson 1967).

The southern part of Lake Michigan shows definite indications of the early stages of eutrophication in shore areas, according to Hiltunen (1967) and Brinkhurst, Hamilton and Herrington (1968). The U. S. Department of the Interior (1968) believed that large areas of the southern end were heavily polluted. This judgment was based on inadequate criteria, however, and although indications of eutrophication do exist, several species typical of oligotrophic conditions still thrive in offshore benthic habitats (Mozley and Alley 1973).

The effects of substratal composition on zoobenthic populations were reviewed by Mozley and Alley (1973). In general the dominant taxa are rarer in coarse, sandy sediments than in finer sands and silts. The most numerous organism, *Pontoporeia*, shows a preference for silts and silty fine sands (Henson 1970; Mozley and Alley 1973). *Oligochaeta* reach largest population sizes in silts (Mozley and Alley 1973). The benthos of larger cobbles, boulders, bedrock, pilings and other solid substrata cannot be sampled by grabs and have a very different taxonomic composition. *Cricotopus* (Chironomidae Orthocladinae), *Gammarus* (Amphipoda) and Naididae (Oligochaeta) are the dominant forms (Bocsor and Judd 1972).

Thermal influences on Great Lakes zoobenthos are very poorly understood. Certain species do not inhabit the warmer, shallower depths in embayments, harbors or near shore, such as *Stylodrilus heringianus*, *Mysis relicta*, *Sphaerium nitidum* and *Pisidium conventus*. *Pontoporeia affinis* is often listed with these, but it has been collected in harbors and river mouths which are not severely polluted (e.g., Willson 1969) and at water temperatures above 20°C in Lake Michigan (Alley and Mozley, in manuscript). Along gradual slopes, the change in temperature is correlated with other environmental

changes such as distance from shore and fineness of sediment grain size. Truchan (1970) studied a thermal plume in the surf zone of Lake Michigan and found larger quantities of detached *Cladophora* and Chironomidae there than in reference areas. However, the thermal effects were confounded with other effects, since the heated water was drawn from a small lake behind the beach rather than Lake Michigan itself. *Gammarus*, *Asellus*, Chironomidae and Ephemeroptera replace *Pontoporeia* in shallow embayments which are not severely polluted. It is not possible to distinguish temperature from many other environmental influences in available field data, so the nature of changes which might result from thermal effluents cannot be predicted. Thermal tolerance studies on *Pontoporeia* in the laboratory (Smith 1972) indicate upper lethal temperatures which are unrealistically low when compared with field observations (Alley and Mozley, in manuscript).

Fish consume at least certain zoobenthos in major quantities. The large size classes of the alewives feed on *Pontoporeia* in Lake Michigan (Morsell and Norden 1968), as do young lake trout (Van Oosten and Deason 1938), bloaters (Wells and Beeton 1963), and whitefish (Ward 1896). Smelt feed heavily on *Mysis relicta* (Creaser 1929). Yellow perch in Saginaw Bay prefer insects, amphipods, crayfish, fish and zooplankton, with larger perch eating larger prey. The yellow perch diet varied according to prey availability (Tharratt 1959). Diets of other species of fish are less well known in the Great Lakes, but suckers, burbot, carp, spottail shiners and sculpins are all likely to exploit zoobenthos as a major food resource.

Knowledge of zoobenthos in Lake Michigan at the higher taxonomic levels, and in regard to offshore depth distribution and major regional trends in species composition of Tubificidae and abundance and life cycle of *Pontoporeia affinis* is relatively extensive. Its composition in species

cannot be predicted in detail for any particular area of the nearshore bottoms however, and practically nothing is known about the food-web interactions of benthic invertebrates with primary producers. The seasonal dynamics of abundance are not known for any species within the first several kilometers from shore, and available data in the nearshore habitats are insufficient for estimates of the year-to-year variations or sampling error.

BENTHOS AND POLLUTION IN THE GREAT LAKES

Benthic macroinvertebrates are often chosen as the primary object of environmental quality assessments. Usual rationale includes the relative stability of zoobenthic distributions in space and time when compared to plankton, fish or water chemistry. Benthos presumably record the effects of transient, harmful events in their species composition for some weeks or months afterwards. Thus the time-summed effects of a pollutant from a localized source will be reflected in the spatial patterns of macroinvertebrate populations in the receiving area. Subsidiary advantages include the relative ease of obtaining repeatable kinds of samples, and less requirements for expensive analytical apparatus and long-term continuous or very frequent measurements in the receiving area (Hynes 1960).

Recently many environmental assessment studies have been summarized in one form or another of species diversity index. This approach is predicated on the need for condensation of large amounts of data into a single parameter which can be utilized in models of pollutional effects (e.g. Hydrosience, Inc. 1972) and on the assertion that pollution effects of many types cause a similar change (i.e. a decrease) in the index. The theoretical reasoning behind such indices is discussed at length by Sanders (1968) and MacArthur (1960), and their widespread use in water quality assessment was stimulated by Wilhm and

Dorris (1968). Their usefulness in the Great Lakes, however, has not yet been established. Indeed, many arguments can be marshalled against use of the most popular types of indices (Mozley 1973b). The strongest one is that species diversity indices for Great Lakes benthic collections are naturally low because of the dominance of *Pontoporeia affinis* and tend to increase (at least initially) with increasing pollution as the proportions of pollution-tolerant Tubificidae increase in the benthos. Therefore species diversity indices cannot be used as linear measures of environmental quality and must be supported by details of species identities and relative abundances for proper interpretation. The advantage of brevity is then lost and there is little point in adding the mathematical complexity of such indices.

Environmental monitoring programs which include studies of the benthic aquatic organisms have been pursued since the early part of this century (Kolkwitz and Marsson 1909). Specific objectives of such studies have never been precisely designated, however. The great majority have focussed on the numbers and specific kinds of macroinvertebrates collected by a particular sampling device or artificial substratum, and the import of resulting data has been assessed by more or less experienced biologists through comparison with similar kinds of measurements in obviously polluted or presumably undisturbed environments. In streams this approach has, on the whole, been very useful (Hynes 1960). In the Great Lakes it has been applied to show temporal changes in shallow basins (Howmiller and Beeton 1971; Britt 1955; Carr and Hiltunen 1965) and the main basin of Lake Michigan (Robertson and Alley 1966). It has also proven useful in defining the spatial extent and degree of generalized pollutional influences in a variety of Great Lakes basins and habitats (Cook and Powers 1964; Brinkhurst 1967, 1969; Hiltunen 1967, 1969; Johnson and Matheson 1968; Veal and Osmond 1968; Schneider,

Hooper and Beeton 1969; Alley and Powers 1970; Howmiller and Beeton 1970, 1971; Kinney 1972; Mozley and Alley 1973). Generalizations about environmental quality can be derived from the species composition and abundance of Tubificidae (Brinkhurst 1969; Mozley and Alley 1973) and Chironomidae (Brinkhurst, Hamilton and Herrington 1968). The decline of Ephemeroptera (Carr and Hiltunen 1965; Britt 1955) or Amphipoda (Cook and Powers (1964) also appears to result from increasing pollution. These and other taxa have changed in Green Bay as pollution has increased (Howmiller and Beeton 1971). In a few cases comparison of species level assessments with those based on the abundances of higher taxa such as Oligochaeta or Amphipoda has shown that extreme pollution may not require lower level identification to demonstrate its regional influences (see review in Mozley and Alley 1973). With the exception of Robertson and Alley (1966) no one has attempted to apply statistical tests to numerical zoobenthic data to distinguish more polluted from less polluted situations. As a result the interpretations of indications of pollution have been essentially qualitative and subjective.

With the increasing public attention to potential influences of large power generating facilities on aquatic environments, there has arisen a new need for sampling designs which will enable objective discrimination between normal variations in zoobenthic species assemblages and various scarcely predictable effects of power plants on these assemblages. This shift from a *posteriori* detection of long-term massive effects of industrial and domestic wastes from large urban centers on relatively broad regions of the lakes or semi-enclosed, shallow basins, to a *priori* programs for detection of possibly localized and more subtle, early effects of heated water on smaller unenclosed shore areas of large basins has raised not a few major challenges for benthic ecologists. We cannot reasonably expect to see massive shifts in species balances or jumps of several orders of magnitude in numbers of zoobenthos which would make detection straightforward. Rather, the biggest challenge is

to determine the relative contributions of sampling error, geographical gradients, seasonal fluctuations and year-to-year variability to the variability of natural populations, and from this, to design programs which will support statistical tests of suspected effects of a power plant. A second challenge is to accumulate sufficient knowledge of the functional interactions between environment and animals in the relatively little-studied habitat to enable a causal analysis of any changes in numbers of zoobenthos which might be detected. While segments of the necessary background information are available in the literature, there is a strong need for on-site studies of species population dynamics and seasonal changes in the composition of benthic species assemblages at each plant.

GOALS OF THE STUDY OF BENTHIC ORGANISMS

The objectives of benthic collections near the Cook Plant have expanded and intensified steadily since the beginning of the survey in 1967. At first, the major taxa of benthic macroinvertebrates were measured once at each site, and contour maps were drawn to show the principal features of abundance and composition in the area (Ayers and Huang 1968). The early surveys were restricted to areas with depths of 10.2 m (35 ft) or less. In 1970, the survey was expanded to include depths as great as 40 m and placed on a seasonal schedule with collections in July, September, November and April of each year. In 1972, "short surveys" of the benthos on a transect extending lakeward from the plant were added, and in July the major survey design was changed to support more elaborate statistical analysis. In 1973, benthos collections from the intake forebay, fish larvae samples and fish trawls were added to the program. Through all these expansions and additions, the primary goal has remained the same: to obtain as thorough a description of

the preoperational zoobenthos populations as appeared necessary to assess the effects of the power plant. Additions to the study have been made partly in answer to several reassessments of the importance of data about the benthos by regulatory agencies, and partly because of experience gained in the earlier surveys.

The results of these studies have been expressed as lists of species found (e.g. Mozley 1973b) and as tables and figures showing relative and absolute numbers per unit area of each taxon, either over the entire area or within a series of depth zones with more homogeneous species assemblages (Mozley and Garcia 1972). Analysis of variance showed significant effects of depth zonation on benthos distributions (Mozley 1973a). The indications of environmental quality shown by the benthos were discussed by Mozley and Garcia (1972). As more data have accumulated and attention has shifted from exploration of the composition and seasonality of zoobenthos species assemblages to detection of effects the power plant may have, analysis has focussed on the inner-outer comparisons and analysis of variance described by Johnson (1973). All data so far have been in the form of numbers of individuals, rather than biomass or more dynamic measures such as turnover rates or gross secondary production.

Certain species have received additional attention, especially the amphipod *Pontoporeia affinis*. The changes in population body-size and reproductive conditions through the months from April to November have revealed the annual cycle of growth and reproduction, and have shown that these differ at different depths (Mozley 1973a). Similar data describe the life cycles of Chironomidae. These midgeflies reproduce about once each year, but at different times for different species, so that the apparent species composition

of Chironomidae larvae in the lake changes from month to month (Mozley 1973a).

These various types of data will enable detection of major changes in the timing of the reproductive cycles, population sizes and composition of the species assemblages which may occur after plant operation. The sensitivity of detection has previously been uncertain, but in this report calculations are included to indicate the magnitude of changes which must occur before they will become statistically demonstrable.

Two kinds of comparative tests can be used in detection of change: comparison with earlier data at stations near the plant, and comparison with simultaneous data collected at reference stations about 8-11 km to the north and to the south of the plant site.

Other goals of the benthos survey include determination of whether unique and vulnerable species or species assemblages occur in the area potentially affected by the plant, and whether the local benthos are unusually important resources for support of fish populations or other aesthetically or economically valuable features of Lake Michigan. The specific responses of zoobenthos to thermal effluents under laboratory conditions have not been studied. The importance of benthic organisms as a forage base for the more abundant fish species is the subject of a recently initiated, stomach-analysis study.

This report covers benthic data collected in 1972 and 1973. It is divided into several topics, or separate studies. The April 1972 survey, which was conducted on the first type of regular station grid, is presented separately in the same format as that employed for the 1972 annual report on benthos (Mozley 1974). A technical change in sampling devices is tested for effects on estimates of kinds and numbers of zoobenthos. The magnitude of change which can be detected at the .95 power level (one minus the probability

of concluding that there was no change when, in fact, there was a change; or Type II error) with different numbers of replicate grab casts is illustrated for total animals. The major and short survey data from July 1972 through August 1973 are presented in a descriptive fashion; more elaborate statistical analysis is underway, but not far enough along to report. The broad spatial and seasonal scope of these studies since 1970 is summarized in graphs to show the preoperational differences between reference regions and the region near the plant, and the monthly and yearly changes in numbers of total animals and major taxa. Finally, the first six months' data on benthic organisms occurring in fish larvae tows are presented as an initial indication of potential benthos entrainment. Although this report is in many ways only one of a continuing series of survey summaries, it also presents the most comprehensive consideration of the ecology of nearshore benthic macroinvertebrates available for the Great Lakes.

METHODS AND MATERIALS

The field methods employed in the Cook Plant benthic surveys since 1970, both equipment and design, have evolved along with the expansion of goals of the surveys and the demands for precision of quantitative estimates. In 1970-71, one observation with the ponar grab was taken at each of 46 stations distributed in an approximately radial grid centered on the plant site in April, July, September and November. In 1972 and 1973, three or five casts were taken with whole or 1/3-sized ponar grabs at 36 stations distributed at random within 4 depth zones along three 3.2-km wide transects from the beach to 40 m of depth for a total of 126 observations in April, July and October; and triplicate observations were taken at up to 9 stations along a transect

beginning at the plant and extending to a depth of about 40 m in the months of May, June, August and September, and in November when weather permitted.

The first radial grid is shown in Figure 1 with the later short-survey stations encircled. The second, systematic-random survey design is exemplified by the July 1973 station map shown in Figure 2. The first survey grid was determined by distances (in miles) from the beach and the plant site. The second grid was determined in transect width and alongshore location by distance from the plant, but in offshore location by random selection of sites within 4 zones defined approximately by the beach and depths of 8, 16, 24, and 40 m. Three stations were placed in each zone and region (N, S or D).

Stations in zone 0 (0-8 m depths) were sampled in quintuplicate with full-sized ponar grabs, both because of variability in zoobenthos and substrates and because so few animals were collected by a single cast. In other zones, 3 casts of the triplex ponar (see following section and Mozley and Chapelsky 1973) were taken at each station and 1/3 of each cast was kept as an observation. On short (9-station) surveys (Fig. 1) 3 full-sized ponar casts were collected at each station in 1972, then in 1973 the 1/3-sized casts were substituted at all stations except DC-0. On the September 1973 survey, full-sized casts were made at DC-0, NDC-.5-1, and SDC-.5-1, i.e., those stations in zone 0, and 1/3-sized casts at the remainder. The changes in surface areas of observations on the various surveys are reflected in the factors which were applied to counts from single observations to convert them to numbers per m² (Table 1).

The treatment of materials from ponar casts remained identical throughout the survey. When casts contained major proportions of sand grains more than 0.5 mm in diameter they were stirred vigorously with a jet of water from

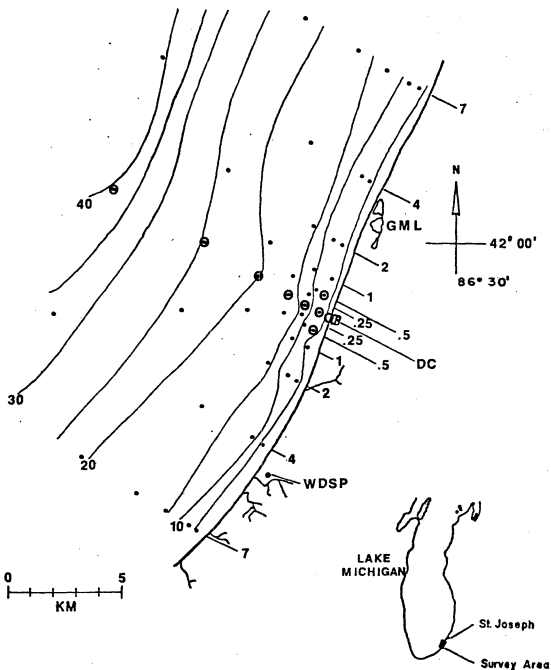


FIGURE 1. The radial grid of sampling stations centered on the Cook Plant (DC), with depths contoured in meters. Transect numbers are designated at the shoreline. Stations were numbered sequentially outward from the shore on each transect. Short survey are encircled. The empty circle at the Cook Plant is station DC-0, which was not sampled on major surveys. WDSP = Warren Dunes State Park, GML = Grand Marais Lakes.

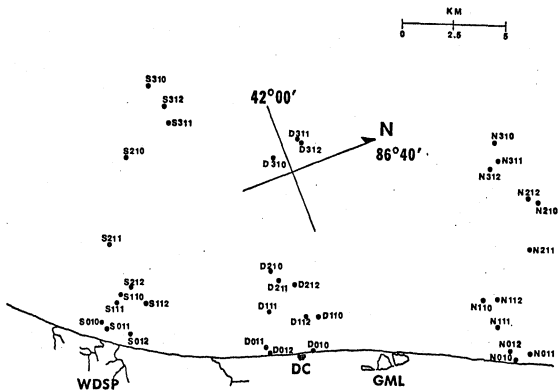


FIGURE 2. Station locations in the systematic-random benthic survey of July 1973. The letter for each station identifies the region (N = north reference, D = Cook Plant, S = south reference) and the first numeral indicates the benthic depth zone. WDSP = Warren Dunes State Park, GML = Grand Marais Lakes; DC = Cook Plant.

TABLE 1. Conversion factors for number per grab cast to number per m^2 (C.F.), number of casts per observation (\bar{X}), number of observations per station (# Rep.), number of stations (# Sta.), and version of ponar grab sampler used, by survey and benthic depth zones through the Cook zoobenthos surveys.

Survey(s)	Station(s) or zone(s)	C.F.	\bar{X}	# Rep.	# Sta.	Ponar version
1970 (all)	all	9.07	2	1	≤46	Old standard
1971 (all)	all	18.13	1	1	≤46	Old standard
1972 April	all	18.13	1	1	45	Old standard
1972 May June August September November	all	20.4	1	3	≤ 9	New standard (fine top screen)
1972 July October	0	20.4	1	5	9	New standard (fine top screen)
July October	1-3	60.6	1/3	3	27	Triplex-center chamber
1973 May June August	DC-0	20.4	1	3	1	New standard (fine top screen until August)
May June August	all other stations	60.6	1/3	3	7	Triplex-center chamber until August then side chamber
1973 September	0	20.4	1	5	3	Triplex-whole grab, or new standard
September	1-3	60.6	1/3	3	5	Triplex-side chamber
1973 April July October	0	20.4	1	5	9	Triplex-whole grab or new standard
April July October	1-3	60.6	1/3	3	27	Triplex-side chamber

a hose in a funnel-shaped tub, after which animals and finer sediments were decanted onto a 0.5 mm-mesh screen (openings 0.5 x 0.5 mm). Most of the coarser material remained in the tub and was discarded after it had been rinsed several times to remove all animals. If little or no sand in the larger grain sizes was present, the entire contents of the grab were washed on the 0.5 mm screen. Screen residues were preserved in carbonate-buffered formalin.

In the laboratory, animals were picked from the residue, counted into taxa which were distinguishable without use of a compound microscope and transferred to fresh, buffered formalin. The skill of technicians who sorted the samples increased beginning with the May 1972 survey, and several distinctions which had not been made previously were begun. The Oligochaeta were separated into *Stylodrilus heringianus*, Tubificidae and Naididae (with a possibility that some *Piguetella michiganensis* might be mistaken for Tubificidae). Sphaeriidae were separated into species of *Sphaerium* and the combined *Pisidium* species. *Pontoporeia* was sorted into size categories or if mature, into reproductive categories, as follows: length < 3 mm, 3-4.9 mm, 5-7 mm, > 7 mm; mature - gravid females, spent females, males of the "*filicornis*" type and males of the "*brevicornis*" type (both types of males were extremely rare). Gastropoda were separated into pulmonates (mostly *Lymnaea*) and operculates (mostly *Valvata*).

Most earlier surveys have now been reexamined for more detailed identification. Earlier reports covered the species composition of samples from July and November 1970 and April, July and November 1971 (Mozley 1974). The reexamination entailed the use of compound microscopes and led to revisions in the counts for several taxa, especially Oligochaeta. The references used

in identification of benthic animals have been cited earlier (Mozley 1974).

Except in cases when Tubificidae, Naididae and Chironomidae have been mounted on temporary slides for species level identification, all materials collected in the Cook benthic surveys are being kept in storage. Permanent slides are being kept for each different species encountered in the above mentioned groups, which are otherwise discarded after identification from temporary mounts.

RESULTS

SPECIES LIST FOR MACROINVERTEBRATES

This report includes several sources for the addition of new species to the record from the vicinity of the Cook Plant in Lake Michigan. Detailed identification of materials from the April 1972 survey is covered below. Some of the many species of macroinvertebrates added as a result of studies of fish larvae tows are discussed below. The third source was materials collected in fishing trawls at depths of 6, 9 and 21 m. Each species in Table 2 is annotated as to whether it is reported for the first time in this list, and in which types of samples it has occurred.

Several taxa remain at higher classification levels than genus or species. In those cases, more than one species may be present in each taxon, and further identification will continue as time permits. Chironomidae, and occasionally other groups, are not positively identifiable in the immature (larval) state. To denote the uncertainty of larval identification, the qualifier "cfr." is added between generic and specific names. When several species may have been observed in any taxon, but not recorded separately, this is signified by the abbreviation for species, plural "spp.".

TABLE 2. Benthic macroinvertebrates identified from collections at the Cook Power Plant through 1973.

Name	Grab sampler	Fish larvae tow	Bottom trawl
Coelenterata			
Hydridae	X	X	
Nematoda	X		
Oligochaeta			
Naididae			
<i>Amphichaeta leydigii</i>		X	
<i>Chaetogaster diaphanus</i>	X	X	
<i>Chaetogaster diastrophus</i>		X	
<i>Nais pardalis</i>	X	X	
<i>Ophidonais serpentina</i>	X	X	
<i>Paranais simplex</i>	X		
<i>Paranais littoralis</i>		X	
<i>Paranais friði</i>		X	
<i>Pristina longiseta</i>	X		
<i>Piguetella michiganensis</i>	X	X	
<i>Stylaria lacustris</i>	X	X	
<i>Uncinatis uncinata</i>	X	X	
<i>Vejdovskyella intermedia</i>		X	
Tubificidae			
<i>Aulodrilus pigueti</i>	X		
<i>Aulodrilus pluriseta</i>	X	X	
<i>Limnodrilus angustipenis</i>	X		
<i>Limnodrilus hoffmeisteri</i>	X		
<i>Limnodrilus spiralis</i>	X		
<i>Limnodrilus cervix</i>	X		
<i>Limnodrilus profundicola</i>	X		
<i>Limnodrilus claparedetianus</i>	X		
<i>Pelosclex freyi</i>	X		
<i>Pelosclex variegatus</i>	X		
<i>Pelosclex multisetosus</i>	X	X	
<i>Pelosclex superiorenensis</i>	X		
<i>Potamothrinx moldaviensis</i>	X		
<i>Potamothrinx vejdoskyi</i>	X		
<i>Potamothrinx bedoti</i>	X		
<i>Tubifex tubifex</i>	X		
Lumbriculidae			
<i>Stylodrilus heringianus</i>	X		
Hirudinea			
Glossiphoniidae			
<i>Helobdella stagnalis</i>	X	X	X
<i>Helobdella elongata</i>	X		
<i>Glossiphonia complanata</i>	X		X

TABLE 2 cont.

Name	Grab sampler	Fish larvae tow	Bottom trawl
Exopodellidae			
<i>Nephelopsis obscura</i>	X		X
Crustacea			
Cladocera			
<i>Eurycercus lamellatus</i>	X	X	
Harpacticoida			
<i>Canthocamptus</i> cfr. <i>robertcookeri</i>	X	X	
Ostracoda	X	X	
Mysidacea			
<i>Mysis relicta</i>	X	X	X
Amphipoda			
<i>Pontoporeia affinis</i>	X	X	X
<i>Gammarus</i> sp.	X		
Decapoda			
<i>Orconectes</i> sp.			X
Arachnoidea			
Hydracarina	X		
<i>Hygrobatas longipalpis</i>		X	
<i>Piona rotunda</i>		X	
<i>Piona</i> sp.		X	
<i>Libertia</i> sp.		X	
Insecta			
Ephemeroptera			
Heptageniidae			
<i>Stenonema</i> sp.		X	
Caenidae			
<i>Tricorythodes</i> sp.	X		
Hemiptera			
Corixidae		X	
Trichoptera			
Hydroptilidae			
<i>Hydroptila</i> sp.		X	
Coleoptera			
Dytiscidae		X	
Elmidae		X	
Diptera			
Ceratopogonidae			
<i>Palpomyia</i> sp.	X		
<i>Culicoides</i> sp.	X		
Chaoboridae			
<i>Chaoborus punctipennis</i>		X	

TABLE 2 cont.

Name	Grab sampler	Fish larvae tow	Bottom trawl
Chironomidae			
<i>Chironomus fluviatilis</i> -group	X	X	
<i>Chironomus anthracinus</i> -group (includes "halophilus-group")	X	X	
<i>Kiefferulus</i> sp.	X		
<i>Cryptochironomus</i> sp. 1	X	X	
<i>Cryptochironomus</i> sp. 2	X	X	
<i>Cryptochironomus</i> sp. 3	X		
<i>Cryptochironomus</i> sp. 4	X		
<i>Demicroptochironomus</i> cfr. <i>vulneratus</i>	X		
<i>Paracladopelma</i> cfr. <i>obscura</i>	X	X	
<i>Paracladopelma</i> <i>tylus</i>	X	X	
<i>Paracladopelma</i> cfr. <i>rolli</i>	X	X	
<i>Parachironomus</i> cfr. <i>demeijerei</i>	X	X	
<i>Harnischia</i> spp.	X		
<i>Glyptotendipes</i> spp.	X	X	
<i>Phaenopsectra</i> (<i>Phaenopsectra</i>) sp.	X		
<i>Dicortendipes</i> cfr. <i>modestus</i>	X		
<i>Stictochironomus</i> sp.		X	
<i>Polypedilum</i> cfr. <i>scalaenum</i>	X	X	
<i>Polypedilum</i> sp. 2	X	X	
<i>Polypedilum</i> <i>fallax</i> -group	X		
<i>Tanytarsus</i> sp. 2		X	
<i>Cladotanytarsus</i> sp. 2		X	
<i>Cladotanytarsus</i> sp. 3		X	
<i>Microsectra</i> sp. 2	X		
<i>Rheotanytarsus</i> sp.		X	
<i>Heterotriisocladius</i> cfr. <i>subpilosus</i>	X	X	
<i>Heterotriisocladius</i> cfr. <i>grimschawi</i>	X		
<i>Psectrocladius</i> cfr. <i>similans</i>	X	X	
<i>Psectrocladius</i> sp. 3 (of Roback)		X	
<i>Psectrocladius</i> sp. 1		X	
<i>Diplocladius</i> spp.		X	
<i>Cricotopus</i> cfr. <i>sylvestris</i>		X	
<i>Monodiamesa tuberculata</i>	X	X	
<i>Potthastia</i> cfr. <i>longimanus</i>	X	X	
<i>Procladius</i> sp.	X		
<i>Conchapelopia</i> spp.	X	X	
Simuliidae			
<i>Simulium</i> sp.		X	
Tipulidae			
<i>Tipula</i> sp.		X	
Gastropoda			
Prosobranchia			

TABLE 2 cont.

Name	Grab sampler	Fish larvae tow	Bottom trawl
Valvatidae			
<i>Valvata sincera</i>	X		X
Bulimidae			
<i>Bulimus</i> sp.	X		
Amnicolidae			
<i>Amnicola</i> spp.	X		
<i>Somatogyrus subglobosus</i>	X		
Pulmonata			
Lymnaeidae			
<i>Lymnaea</i> spp.	X		X
Physidae			
<i>Physa</i> sp.	X		X
Pelecypoda			
Sphaeriidae			
<i>Sphaerium nitidum</i>	X		X
<i>Sphaerium striatinum</i>	X		X
<i>Sphaerium transversum</i>	X		
<i>Sphaerium securis</i>	X		
<i>Sphaerium corneum</i>	X		
<i>Pisidium</i> spp.	X		X
Acanthocephala (free in sample)	X	X	
Platyhelminthes			
Turbellaria	X		

The hydras were not well preserved in our methodology and may be lost during collection. They were rare in grab samples and fish larvae tows. Nematoda were certainly undersampled, but sometimes they were very abundant in grab samples. Most Naididae were found in fish larvae tows, indicating their proclivity as a group toward swimming. Their comparative rarity in grab samples was possibly due to their small size and delicate structure, which would cause them to be destroyed or washed away in the screening process. Most other Annelida were large enough to be retained by the screens (unless they actively crawled through the mesh) at least in mature size ranges. Copepods, ostracods, and cladocerans were small enough to escape. Little effort has been expended to count or identify them so far, and several (additional) species may be present in each group at the Cook Plant. Trawling captured crayfish (*Ormonectes*), while the grab did not, because of their rarity and ability to avoid grab samplers. Many of the insects were detected only in fish larvae tows, partly because that method samples a much larger amount of habitat, and partly because some of them prefer solid substrates and would be rare or absent from bottom types which were sampled with grabs. Water mites and *Chaoborus* are probably planktonic most of the time. Mollusca of solid substrata may not be completely sampled yet, since they do not swim or become suspended in the water column, and no sampling of solid substrates (e.g., rip-rap) has been conducted at the Cook Plant. Snails, especially, can be expected to be abundant and diverse on solid substrates. Notwithstanding the large increase in recorded species over the last report, further large increases in this number could doubtless be achieved by identification of material in storage and addition of other sampling procedures.

GRAB COMPARISON TESTS: SAMPLING EFFECTIVENESS OF THE TRIPLEX PONAR

Use of a modified version of the standard ponar grab-sampler was instituted

simultaneously with the systematic-random survey design in July 1972. This version has three internal chambers with independent access, so that collections from as little as one-third the cross-sectional area of the usual ponar grab could be made when total animal abundances were high (Fig. 3, Mozley and Chapelsky 1973). By reducing the surface area of each observation, it was possible to take more individual observations with no increase in laboratory sorting time.

In the past, different types of grab-samplers have been found to produce very different estimates of zoobenthic population sizes (Flannagan 1970), so it was necessary to compare the standard ponar grab-sampler used before July 1972 with the triplex version to see if there were systematic differences in number of animals collected. The internal chambers, although of equal cross-sectional area, might conceivably differ in efficiency among themselves as well. Tests were conducted on 23 April 1973, with three versions of the ponar (the triplex, the standard model for earlier Cook surveys, and the commercial model used by other investigators) to find out what differences, if any, existed among the grabs in ability to collect zoobenthos.

Two kinds of tests were conducted. First, tests were made of the differences among numbers of zoobenthic animals per grab cast for the three versions, with the three triplex chambers from each cast summed for a single observation. Ten casts of each version of grab were made in cyclical alternation as the ship drifted slowly across the station. The ship returned to the upwind side of the station after 10 and 20 casts. Two stations were sampled in this way, SDC-.5-1 (5 m deep) and DC-4 (22 m deep). Each cast or chamber of the triplex was processed in exactly the same way as regular survey collections. The second kind of test was a comparison of the side chambers (20 observations from 10 casts) versus the center chambers (10 observations from 10 casts) of

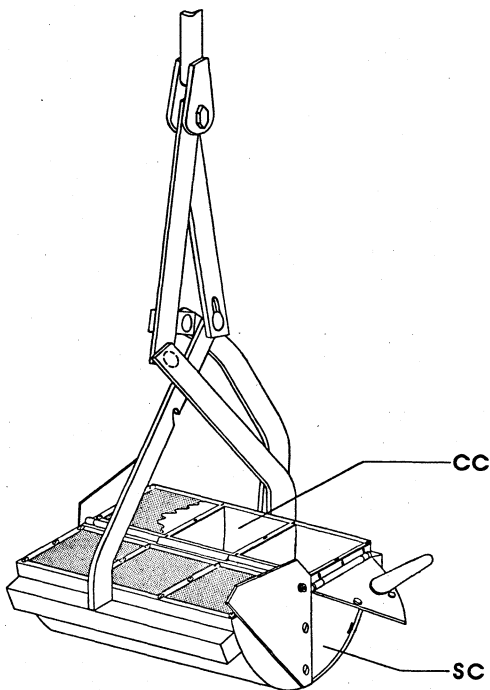


FIGURE 3. Triplex version of the ponar grab sampler with jaws shut and one side door open. CC = center chamber, SC = side chamber (from Mozley and Chapelsky 1973).

the triplex version at each station. The extensive replication produced in the course of this study was also useful in predicting the levels of precision of estimates of the mean which can be achieved for various taxa with the usual number of replicates.

Table 3 lists some structural differences among the three versions of ponar. The cross-sectional surface area, or surface area of bottom which is

TABLE 3. Dimensions and weights of the standard Great Lakes Research Division, commercial and triplex versions of the ponar grab-samplers.

Grab	Jaw spread (cm) * ¹	Jaw width (cm)	Sampled area (cm ²)	Hinge height (cm)	Weight (kg)
Standard	20.5	23.6	485	7.8	16.3
Commercial	22.3	23.2	515	11.2	19.4
Triples	21.0	23.6	495	7.8	18.4

*¹ Suspended by handle with trigger engaged.

enclosed in a cast of the grab, is difficult to measure precisely because of a slight spreading of the jaws which can occur when the open grab contacts bottom. A difference of 1-2% in surface area estimate can arise from measurement of the width of the grab from the inner side, center of the edge, or outer side of the jaw plates and guard plates. Therefore, differences in entrapped area between the standard and triplex versions are considered negligible, while a correction factor of 5% has been applied to data from the commercial version so that numbers per grab cast are equivalent for the commercial version and the other two. After conclusion of the experiment, it was discovered that the standard version had been fitted by mistake with a finer screen than the triplex (0.35 mm vs. 0.5 mm). The commercial version was

fitted with a #30 mesh screen (0.57 mm). The commercial version was heaviest and the standard version the lightest. Also, the commercial version had an opening large enough to allow individuals of most taxa of zoobenthos to escape at the top of the guard plates and below the hinge when the grab was cocked open.

Cast volumes in the sandy substrates of the two stations were relatively small (Table 4). Analysis of variance of the mean volumes for the three

TABLE 4. Volumes of sand collected by the three versions of the ponar grab at two stations, expressed in milliliters. Each mean and standard error represents 10 observations. Lines under means connect values not significantly different (see text for test description).

Station	Commercial	Ponar version triplex	Standard
SDC-.5-1 (5 m)	918 \pm 76	965 \pm 131	1147 \pm 99
DC-4 (22 m)	586 \pm 58	711 \pm 20	827 \pm 95

versions (volumes of three chambers combined for each cast of the triplex) revealed no significant differences among versions at station SDC-.5-1, but at DC-4 the F-ratio was significant at the .025 level. Tukey's "W-method" for testing differences among mean volumes indicated that the standard version collected significantly ($P < .05$) more sediment than the commercial version, but the triplex was intermediate between the two and not significantly different from either. This was surprising, since the standard version was the lightest and the commercial version the heaviest of the three grabs. The jaws' edges were thicker and blunter in the commercial version and may have bitten less

effectively than those of the standard version. Perhaps the finer screen on the standard version retained the fine sand at station DC-4 better than the coarser screens on the other two versions during retrieval from the bottom. As will be shown below, the means of total animals and several separate taxa collected by the commercial version were larger (but not significantly different) from those collected by the standard version, so the greater sediment volume collected by the latter did not yield larger numbers of zoobenthos.

Before the sediment collected by the grabs was sieved for zoobenthos, its overall grain size and visible characteristics were described and recorded by E. Seibel. The shallow station (SDC-.5-1) yielded two principal categories of sediments, "fine sands" and "medium-to-coarse sands." Division of observations regardless of version of ponar into these two categories revealed no significant difference (t-test) among means of total animals. At DC-4 all sediments were described as "silty fine sand."

Table 5 shows means and standard errors of total animals and the more abundant taxa of zoobenthos obtained in the comparison experiment at both stations. The triplex version always collected a higher mean number of animals regardless of station or taxon. At station SDC-.5-1, the analysis of variance of total animals showed significant ($P < .05$) variance contribution due to ponar version and the triplex mean significantly larger ($P < .05$) than the standard version mean as determined by Tukey's "W-method" for least significant range (*a posteriori* comparison). The commercial version was intermediate between the other two in total animals collected and not significantly different from either. Although the differences among means were much larger at station DC-4, this was mainly due to a single triplex cast which yielded 502 *Pisidium* and another which contained 179 Tubificidae, both of which were almost 3 standard deviations above the mean for all triplex casts in the respective

TABLE 5. Tests for differences in numbers of zoobenthos collected by the three versions of the ponar grab at two stations, expressed as mean and standard error of numbers per grab. Test methods are described in the text. $F_{.05}[2,27] = 3.36$. Underlining shows results of Tukey's "W-method" for differences.

Station	Taxon	ANOVA	LSR	Standard	Commercial	Triplex
SDC-.5-1	Total animals	3.51*	3.1	<u>2.8\pm 0.6</u>	<u>4.6\pm 1.2</u>	<u>6.1\pm 0.7</u>
	<i>Chironomus fluviatilis</i> -group	2.26	-	1.8 \pm 0.7	3.3 \pm 0.9	4.0 \pm 0.7
DC-4	Total animals	2.21	-	88.3 \pm 20.6	94.0 \pm 18.4	182.8 \pm 56.9
	<i>Pontoporeia affinis</i>	-	-	32.2 \pm 7.4	25.6 \pm 6.6	41.2 \pm 8.3
	<i>Stylodrilus heringianus</i>	0.88	-	18.9 \pm 1.9	10.0 \pm 4.0	13.0 \pm 5.0
	Total Tubificidae	-	-	18.9 \pm 6.1	25.9 \pm 11.6	28.1 \pm 16.9
	<i>Pisidium</i> spp.	-	-	21.3 \pm 8.0	19.6 \pm 3.2	73.2 \pm 48.2
	<i>Sphaerium nitidum</i>	1.68	-	7.4 \pm 2.2	5.4 \pm 1.6	15.8 \pm 7.0
	Total Chironomidae	-	-	3.2 \pm 0.8	3.9 \pm 0.8	4.4 \pm 0.9

* Significant at .05 level.

taxa. This caused within-grab-version variance to be large, and may have masked real differences due to grab version.

Evidently some feature of the standard version caused a reduction in the number of animals collected under conditions found at station SDC-.5-1. The most likely feature was the finer mesh of the top screen and the resulting smaller percentage of open area in the screen through which water could flow during descent. The greater resistance to flow would increase the shock wave

which precedes the grab and could blow animals on or near the surface away from the area beneath the grab. Another possible explanation would be the lighter weight of the standard version, which might have caused it to bite less deeply and miss some burrowing animals.

Our standard version of the ponar grab was weighted until it matched the triplex weight and the top screen was exchanged for a 0.5-mm mesh one in late July 1973. Later increases in numbers of zoobenthos relative to those collected in zone 0 on systematic-random surveys and at shallow stations in monthly surveys from May 1972 through June 1973 could be due partly to this change.

Since the contents of the three chambers of the triplex were kept separate, it was possible to test for differences in numbers of animals collected by different chambers. There was no reason to expect that the two side chambers would differ from each other in any systematic way, so no attempt was made to record the particular side of the grab from which an observation was taken. Comparisons were conducted with a two-sample student's "t-test" between all observations from side chambers ($n=20$) and those from the center chamber ($n=10$) at both stations (Table 6).

The only significant difference ($P<.05$) was at station DC-4 for *Pontoporeia affinis*. The center chamber collected significantly fewer amphipods than the side chambers. When the *Pontoporeia* were divided into those longer or shorter than 3 mm, only small individuals differed significantly ($P<.05$) between center and side chambers. It was noted that as the contents of the chambers were being rinsed into tubs, there was some leakage of fine sand from the center into the side chambers near the point where the jaws met. On the assumption that the side chambers were receiving the small *Pontoporeia* at the expense of the center chamber as a result of this leakage, additional

TABLE 6. Center vs. side chamber comparisons with the triplex version of the ponar at two stations.

Station	Taxon	Center n=10		Sides n=20		Student's t-statistic (df=18)
		$\bar{x} \pm s$	\bar{x}	$\bar{x} \pm s$	\bar{x}	
SDC-.5-1	Total No's.	1.6 \pm 0.4		2.3 \pm 0.4		1.09
	<i>Chironomus</i> <i>fluviatilis</i> - group	1.3 \pm 0.3		1.4 \pm 0.3		-
DC-4	Total No's.	75.5 \pm 49.1		53.7 \pm 9.3		-
	<i>Pontoporeia</i> total	6.5 \pm 2.4		17.4 \pm 2.8		2.42*
	<i>Pontoporeia</i> <3 mm	5.6 \pm 2.1		15.8 \pm 2.6		2.46*
	<i>Pontoporeia</i> >3 mm	0.9 \pm 0.3		1.6 \pm 0.3		1.41
	Total Tubificidae	5.2 \pm 2.4		12.3 \pm 6.5		-
	<i>Stylodrilus</i>	3.8 \pm 1.5		4.6 \pm 1.7		-
	<i>Pisidium</i>	46.9 \pm 41.5		13.2 \pm 3.6		-
	<i>Sphaerium</i> <i>nitidum</i>	9.0 \pm 6.1		3.4 \pm 1.0		1.18
	Total Chironomidae	1.6 \pm 0.5		1.4 \pm 0.3		-

* Significant at .05 level.

machining was done on the jaws to provide for a tighter seal between chambers. Also, one of the side chambers was used as the 1/3 ponar sample in subsequent surveys to minimize the effect of leakage from the center to the side chambers.

Another explanation would be that the shock wave which preceded the ponar during descent blew the smaller organisms near the sediment-water interface

away from the center chamber more than it blew them away from the side chambers just before impact. If this were true, the side chambers would also be more representative of the true population. Sealing work on the jaws and use of the side chambers was done for the first time on the August 1973 short survey (Table 1).

SAMPLING INTENSITY AND DETECTION OF ZOOBENTHIC POPULATION CHANGES

The large number of replicate ponar casts collected during the grab comparison study also illustrated the effects of greater than usual sampling intensity on the precision of estimates of mean numbers per m^2 , and on the ability to detect compositional changes in the zoobenthos species assemblages as indicated by the rank order of common species at two particular stations. Moreover, the same tests could be run with observations from both full-sized and 1/3-sized ponar casts. Finally, these and other data could be used to calculate the amounts of change in mean numbers which must occur before the differences would be judged to be statistically significant.

The cumulative effect of continuing replication on estimates of the means and standard errors is illustrated in Figure 4 for station SDC-.5-1 and Figures 5 and 6 for station DC-4. At the shallower station (Fig. 4) the standard version of the ponar collected very few zoobenthos in the initial casts, while the other two versions collected many more than the final mean number. After approximately four casts, the standard and triplex versions reached a relatively precise and accurate estimate of the mean of total animals in each which resulted from ten casts, while the cumulative mean from the commercial version decreased from the third through the tenth cast, and had relatively large standard errors. This was due to a denser patch of animals encountered in the third cast. As was stated above, the standard version collected significantly ($P < .05$) fewer total animals than the triplex.

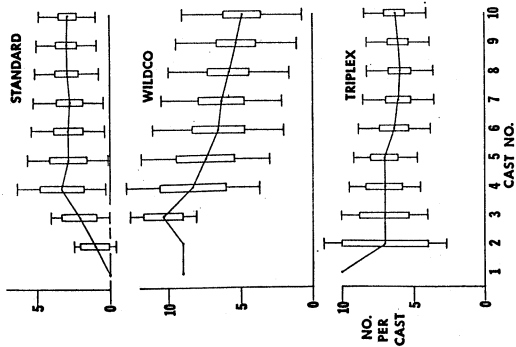


FIGURE 4. Comparison of the cumulative mean number of total animals per cast among the three versions of ponar grabs at station SDC-5-1 in April 1973. Bars show standard errors and brackets show standard deviations. Casts are arranged in the order in which they were taken.

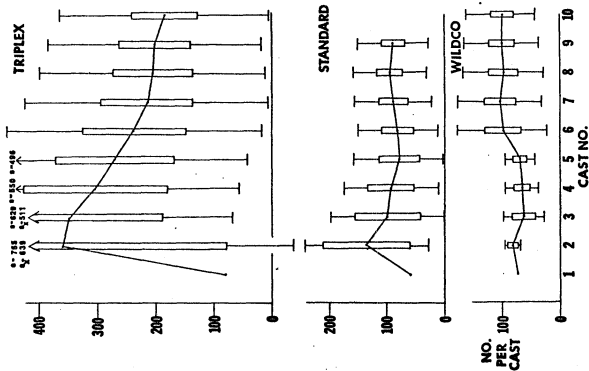


FIGURE 5. Comparison of the cumulative mean numbers of total animals per cast among the three versions of ponar grabs at station DC-4 in April 1973. Bars show standard errors and brackets show standard deviations. Casts are arranged in the order in which they were taken.

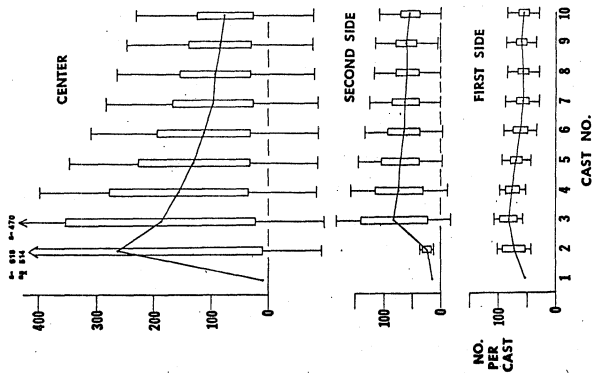


FIGURE 6. Comparison of the cumulative mean numbers of total animals per cast among the three chambers of the triplex ponar grab at station DC-4 in April 1973. Bars show standard errors and brackets show standard deviations. Casts are arranged in the order in which they were taken.

After the third cast, the commercial and triplex versions gave similar estimates of the mean.

At the deeper station (Fig. 5) a dense patch of Sphaeriidae was encountered on the second cast of the triplex version, and further casts gradually reduced the mean and standard error toward those for the other ponar versions. There were no significant differences among the means for the three versions at this station. The final (after the tenth cast) mean and standard error for each series depended essentially on whether or not a dense patch of animals was encountered.

Since the three versions were cast in alternating, cyclical order, one would expect to find parallel trends in the means for all three, but these figures show that no such trends occurred. We may presume that the patches were smaller than the distance which the boat drifted between casts (about 20-30 m, based on an estimated drift on that date of 2.5 km/hr). Figure 6 shows that the patch of Sphaeriidae in the second cast was almost entirely confined to the center chamber. Further evidence for the small areal scale of patches comes from analysis of variance on all the more numerous taxa in the three triplex chambers within and among casts: the variation between casts was not significantly greater than the variation of chambers within casts for any common taxon. Data from the 1/3-sized chambers of the triplex ponar (Fig. 6) are at least as much affected by dense patches of animals as those from whole ponar casts.

The precision of observations from 1/3-sized triplex chambers was not as fine as for the full-sized observations. If precision is measured in units of D, where

$$D = \frac{\frac{S}{\bar{x}}}{\bar{x}} = \frac{S}{\sqrt{n} \bar{x}}$$

then the effect of continued sampling on precision can be illustrated by increasing the value of n , or number of observations. This calculation is based on the assumption that a good estimate of the standard deviation (S) is available and that no further dense patches are encountered. After ten casts, $D = 0.31$ for total animals in whole casts of the triplex version (see Table 5), and the two side chambers and center chamber had D 's of 0.16, 0.32 and 0.65, respectively. The center chamber had poor precision of the estimated mean because the large sample of clams occurred almost entirely within it (483 versus 74 and 18 in the two side chambers from the cast). Since no patches approaching this density were encountered in any of the other 29 full-sized ponar casts, we may presume that the chances of collecting so many in a single chamber at that station are very small, *i.e.* this observation was freakish. To better compare the relative precision of single chambers and full-sized casts, data from the other two versions of the ponar may be set against those from the two side chambers of the triplex version. The commercial version gave a D of 0.20 and the standard version a D of 0.23. Since three times as many animals must be sorted and counted to analyze full-sized ponar casts as for single chambers of the triplex, relatively little advantage would have been achieved in precision at the expense of much larger amounts of laboratory work.

The abundant taxa at DC-4 differed widely with respect to precision of numerical estimates after 10 casts of the triplex (center chamber), from $D = 0.31$ for Chironomidae to $D = 0.88$ for *Pisidium*. *Pontoporeia* had relatively homogeneous abundances from cast to cast, with $D = 0.37$, while total animals showed the effects of the dense patch of *Pisidium* with $D = 0.65$. As pointed out above, the side chambers yielded more precise estimates, but the rank order of taxa by precision of estimated means was about the same.

Pontoporeia and Chironomidae had the better precisions and Tubificidae and *Stylodrilus* had the worse ones. The clams were less variable in side chamber data, which contained no dense patches to compare with the one in a center-chamber observation.

The rank order by abundance of the more common taxa (arbitrarily defined as those contributing more than 5% of total animals) gives an indication of the quality of the benthic environment in a traditional, subjective fashion. The number of casts required to attain a stable rank order should provide some insight into the possibilities of precision in describing benthic species associations for indicative purposes. The overall percentage composition, from 30 casts of all ponar versions combined, is given in Table 7 and the cumulative percentage compositions from cast to cast are shown for both SDC-.5-1

TABLE 7. Common taxa of zoobenthos at the two stations, with percentages of total animals and frequency of occurrence for each.

Station	Taxon	% Total animals in all casts	% Occurrence in all casts
SDC-.5-1	<i>Chironomus fluviatilis</i> -gr.	67.4	87
	<i>Paracladopelma</i> cfr. <i>rolli</i>	5.1	20
	<i>Pontoporeia affinis</i>	5.8	23
	Immature Tubificidae	5.1	13
DC-4	<i>Pontoporeia affinis</i>	26.9	100
	<i>Pisidium</i> spp.	31.9	97
	<i>Sphaerium nitidum</i>	7.7	76
	<i>Stylodrilus heringianus</i>	7.6	93
	<i>Limnodrilus hoffmeisteri</i> *	11.4	62

* *Limnodrilus hoffmeisteri* refers only to identifiable, mature specimens; an approximately equal number of immatures in this sample must have included many *L. hoffmeisteri*, so the stated frequency and percentage of abundance are only minimum estimates.

and DC-4 in Figures 7 and 8. The cumulative percentages were calculated on casts in the order they were collected, regardless of ponar version (total $n=30$). At station SDC-.5-1, one taxon eventually contributed 67% of total animals (*Chironomus fluviatilis*-group), and an additional three common taxa contributed 16%. Three of the four common taxa fall into the proper order after eight casts, but the fourth was not even present until the sixteenth cast. At station DC-4, it made little difference whether full-sized (Fig. 8) or 1/3-sized casts were used; the rankings of common species fell into proper order after about nine or ten casts. At that station, the most abundant taxon (*Pisidium*) contributed only 32% of total animals and the five common taxa contributed about 86% together. All the common taxa were detected within the first three casts.

While the precision of estimates of means gives an indication of the variability of the data, further calculations can provide an estimate of the amount of change which must occur in a given station or zone mean over time before it will be judged significantly different. Sokal and Rohlf (1969) give a formula for determining the number of replicates which would be necessary to accept as significant a true difference in means of two populations. Their formula can be transposed to express the least size of a true difference which would be statistically significant, based on a given number of replicate observations. This least detectable true difference (δ) is defined for both significance level ($P = .05$) and power, or $1-\beta$ (chance of the type II error, $\beta = .05$) in the calculation for Table 8. The effect of one of the usual transformations is shown for the same data.

Under conditions found at these two stations in April 1973, and assuming 10 replicate observations, more than a doubling of the mean of total animals per cast would have been necessary at SDC-.5-1 and more than a tripling at

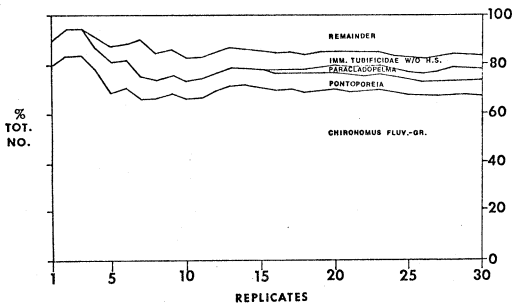


FIGURE 7. Cumulative percentages of total animals due to each taxon which contributed 5% of the final total cast (= replicate) by cast at station SDC-.5-1 in April 1973 with casts arranged in the order in which they were taken (regardless of ponar version).

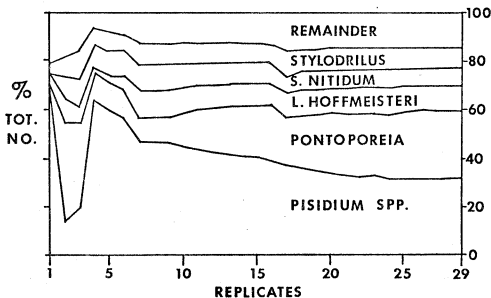


FIGURE 8. Cumulative percentages of total animals due to each taxon which contributed 5% or more of the final total, cast (= replicate) by cast at station DC-4 in April 1973 with casts arranged in the order in which they were taken (regardless of ponar version). One cast was partially lost during analysis.

TABLE 8. Least detectable true differences from means of total animals in grab casts in two depth zones of the D region in April 1973. In zone 0 (SDC-5-1), the data represent casts of the standard version of the ponar, while in zone 2 (DC-4, D 2's) they represent the center chamber of casts of the triplex version. The formula for least detectable true difference for $p = .05$ and power = .95 (Sokal and Rohlf 1969) is:

$$\delta = \sqrt{2} \left(t_{.05[2(n-1)] + t_{.10[2(n-1)]} \right) S_{\bar{x}}$$

The y-values for each station are based on the transformation $y = \log_{10}(x+1)$. "n" refers to the number of ponar casts per mean.

$LO_x = \text{antilog}(\bar{y} - \delta_y)$; $UP_x = \text{antilog}(\bar{y} + \delta_y)$; GM = antilog($\bar{y} - 1$)

Station	n	\bar{x}	$S_{\bar{x}}$	δ	$\bar{x} - \delta$	$\bar{x} + \delta$	\bar{y}	$S_{\bar{y}}$	$\delta_{\bar{y}}$	GM	LO_x	UP_x
SDC-5-1	10	2.8	0.60	3.25	-0.45	6.05	0.52	0.08	0.42	2.31	0.26	7.71
DC-4	10	75.5	49.1	266.3	-190.8	341.8	1.45	0.19	1.03	27.2	1.63	301.0
D 27	3	336.3	123.4	856.5	-520.2	1192.8	2.48	0.15	1.04	310.0	27.5	3310.0
D 28	3	58.0	27.4	190.2	-132.2	248.2	1.66	0.23	1.60	44.7	0.15	1819.0
D 29	3	77.0	16.5	114.5	-37.5	191.5	1.87	0.11	0.76	73.1	11.9	425.6
D 2	9	157.1	58.1	317.6	-160.5	474.7	2.00	0.15	0.82	99.0	14.1	659.7

DC-4 before the statistical probability of true difference would have been acceptable. In fact, the difference between the standard ponar version, on which this test is based, and the triplex version at station SDC-.5-1 was slightly larger than the calculated δ , and was accepted as being significant (see Table 5). In these two cases, the effect of transforming the data before calculation of δ was to reduce the least detectable decrease in the mean to a value less than the mean, so that a mean of 0 (absence of animals from the new sample) would be considered significantly different (permit rejection of the null hypothesis).

Table 8 also gives the results of similar calculations for the three stations sampled in zone D 2 the following day. The δ 's for untransformed data were between 1 1/2 and 2 1/2 times the mean, and widely overlapped zero. For the transformed data, δ 's were less than the mean, and when de-transformed show that eradication of animals from any of the three stations would be considered a significant difference. The limits for detectable increases in the mean were much higher than for untransformed data, however, so that transformation seriously lowered sensitivity to increases. When the three stations were combined as a single sample (N=9) from zone D 2, the differences between δ 's calculated from transformed and untransformed data were less.

These estimates of δ for specific stations and zones cannot be extended to answer the question of what magnitude of differences could be detected on the average over the entire survey area, however. For this, more information about the within-zone variability of numbers of total animals in grab samples is needed. The most extensive source of such information is the systematic-random surveys. A one-way analysis of variance was performed for within-zone versus between-zone variability in each of the four major surveys of this type which have been sorted so far. Since grab sizes and numbers of

replicates were not the same in zone 0 and zones 1-3, the two sets of data were analyzed separately in each month. The sums of squares from within-zone variability from the ANOVA's were summed over the four surveys and divided by the summed degrees of freedom to obtain an average, within-zone mean square over all surveys and zones. The ANOVA tables are given in Table 9. In zone 0, each cell

TABLE 9. Analysis of variance tables for within versus between zone comparisons of variances of total animals in the systematic-random surveys.

Survey	Source	SS	df	MS	F _s	
July 72	Between regions	21,253	2	10,626	1.184	NS
Zone 0	Within regions	376,854	42	8,973		
Zones 1-3	Between zones	1,365,321	8	170,665	9.816***	
	Within zones	1,251,805	72	17,386		
Oct. 72	Between regions	284,343	2	142,172	3.288*	
Zone 0	Within regions	1,815,647	42	43,230		
Zones 1-3	Between zones	1,112,678	8	139,085	14.815***	
	Within zones	675,911	72	9,388		
Apr. 73	Between regions	27,769	2	13,884	9.644***	
Zone 0	Within regions	38,870	27	1,440		
Zones 1-3	Between zones	2,680,266	8	335,033	5.508***	
	Within zones	4,378,890	72	60,818		
July 73	Between regions	164,874	2	82,437	4.329*	
Zone 0	Within regions	799,773	42	19,042		
Zones 1-3	Between zones	1,477,914	8	184,739	2.886**	
	Within zones	4,608,443	72	64,006		

* Significance at .05 level; ** Significance at .01 level; *** Significance at .001 level.

included 15 replicates except in April 1973. In that survey, one station each in the north reference and Cook regions was deeper than the zonal depth limit of 8 m, and so was eliminated from the calculations. A station from which one

of the five replicates was lost, was dropped from the south reference set to balance the cells. Therefore, only two stations with a total of 10 observations were used in the analysis. In zones 1, 2 and 3, there were three regions and three zones in each region for a total of nine cells ("zones") and three observations at each station for a total of nine observations per cell.

At this point in the course of Cook benthos analysis, extensive discussion of the other ANOVA results is passed over, but it can be seen from Table 9 that differences among zones were the rule rather than the exception. In the deeper zones, much of this was undoubtedly due to the depth effect (see Mozley 1973a), but differences also occurred in zone 0 among regions. The variance estimate (mean square) derived from these calculations was used to determine the effect of sampling intensity on the size of the least detectable true difference (δ) (Table 10). This is illustrated for zone 0 in Figure 9 and for zones 1-3 in

TABLE 10. Intermediate steps in the computation of δ from the ANOVA tables in Table 9 in units of total animals per m^2 . The within-cell (=region or zone) sums of squares and degrees of freedom are summed to form the basis of mean square calculation. See Figures 9 and 10.

Zone(s)	Sums of squares	Degrees of freedom	Mean square	Estimated standard deviation within cells	Grand mean of total animals
0	3,031,144	153	19,811	140.8	2,356
1-3	10,915,049	288	37,899	194.7	17,192

Figure 10. In zone 0, the proportional advantage of further replication was very small after 5 or 6 replicates. Tripling the number of replicates to 15 (the number collected in each zone on major surveys) decreased δ by about half, from $7446/m^2$ to $3917/m^2$. In zones 1-3, the least detectable true difference in total animals

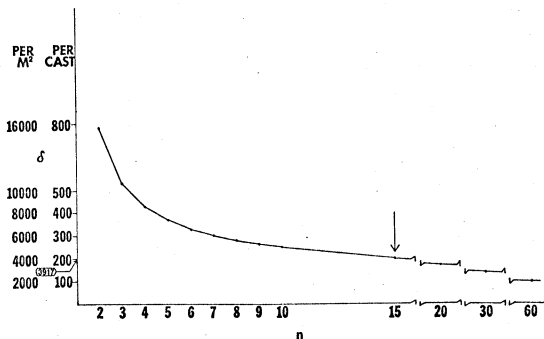


FIGURE 9. Theoretical relationship between n (= number of casts) and δ (= least detectable true difference, in this case for total animals), based on the estimate of variance from the 1972-73 major surveys in zone 0 of regions S, D and N. The arrows indicate the value of δ for $n = 15$, the number of casts in each zone 0 on systematic-random surveys.

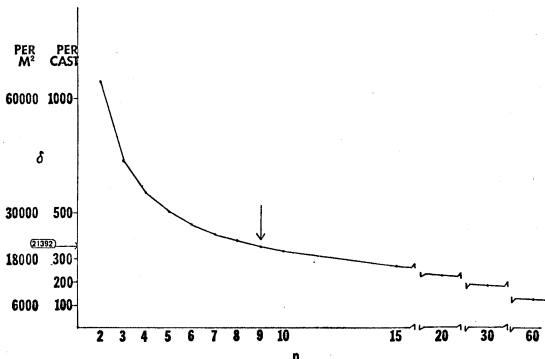


FIGURE 10. Theoretical relationship between n (= number of casts) and δ (= least detectable true difference, in this case for total animals), based on the estimate of variance from the 1972-73 major surveys in zones 1, 2 and 3 of regions S, D and N. The arrows indicate the value of δ for $n = 9$, the number of casts in these zones on systematic-random surveys.

per cast was larger, but the grand zonal mean was larger, also. After nine replicates, δ was $21,392/m^2$. The larger values for δ reflect the broad variations in numbers per cast within stations and zones which were also illustrated in Figures 4, 5, and 6 and Tables 5, 6, and 8.

The variances were quite different from month to month (Table 9). Non-homogeneity of variances violates one assumption of this test, and final answers to the question of the magnitude of the least detectable true difference will require transformation of the data.

The grand mean for total animals over all months and observations in zone 0 was $2356/m^2$, so later means as large or larger than $2\frac{2}{3}$ times this amount would be judged significant with equal replication. In zones 1 to 3 the grand mean was $17,192/m^2$, and a detectable change would require an increase in this mean by a factor of $2\frac{1}{4}$. Future means of 0 would not be judged significantly different at the stated significance and power levels in either depth range.

THE 1972-73 GRAB-SAMPLER SURVEYS

Species composition, April 1972

The April 1972 zoobenthos survey was the last in a series of 8 conducted on the original 46-station grid. It was the sixth to be analyzed at the species level (September surveys omitted). The results of such analysis of the preceding ones were presented, along with the basic data, by Mozley (1974). Like those surveys, that of April 1972 was initially sorted to six major taxa and the data reported by Mozley (1973a). As for 1971 surveys, a single cast of the full-sized ponar was made at each station. All grab casts from the April 1972 survey have now been analyzed at the species level.

Table 11 gives the basic data for April 1972, and Figures 11 and 12 show the means for most taxa by benthic depth zone at the same scales and in the

same manner as the 1970-71 data in Part XX (Mozley 1974). Means of total animals were practically identical between April 1971 and April 1972, except that zone 1 had somewhat larger numbers in 1972. Numbers of *P. affinis* were slightly lower and numbers of Tubificidae were higher, especially in zone 1, in April 1972 than in April 1971. There were more *Potthastia* cfr. *longimanus* and *Monodiamesa tuberculata* in zones 1-3 in 1972, but these chironomid larvae were still relatively minor constituents of the zoobenthos. Most of the more abundant, larger chironomid larvae were not strongly different in the two Aprils, but *Chironomus fluviatilis*-group was several times more numerous in zones 0 and 1 in 1972 than in 1971.

The size-class distribution of *Pontoporeia* populations in benthic depth zones 1-3 in April 1972 indicated that release of the young was slightly later in 1972 than in 1971, and this could account for the April differences in *Pontoporeia* abundance (lower in April 1972). These data are presented along with other 1972 data and 1973 data in a later section.

Naididae were represented only by *Uncinatis uncinata* (very rare, zone 1 only) and *Piguetella michiganensis* (rare in zones 0 and 2, common in zone 1) both of which were less numerous than in July or November 1971.

Several new species were reported in this survey, as predicted in Part XX. Rare species encountered for the first time include: ?*Somatogyrus subglobosus* (Gastropoda), *Paracladopelma* cfr. *rolli*, *Demicyptochironomus* cfr. *vulneratus*, *Conchapelopia* sp., (Chironomidae), *Peloscolex superioren-sis*, *Potamothrix bedoti* and *Rhyacodrilus coccineus* (Tubificidae). Species which have been present before but not identified separately or to the species level include *Ammicola* sp., *Valvata sincera* (Gastropoda), *Sphaerium corneum* (previously as "sp. 1"), and *Microsectra* sp. 2 (as Tanytarsini spp.).

TABLE 11. Cook Plant benthos survey 12 April 1972 (#/m²). Key to abbreviations at end of table.

CHIRONOMIDAE

Station	<i>Chironomus</i>			<i>Cryptochir</i>		<i>Paracladop</i>		<i>Heterotriss</i>		<i>Proc</i> sp.
	fluv	anth	tail	sp. 2	sp. 3	obsc	roll	subp	grim	
NDC-2-1										
NDC-1-1										
SDC-2-1	254			36						
SDC-4-1	272									
SDC-7-1	272				18					
NDC-4-1				18						
NDC-.5-1										
SDC-.5-1	490			181	36		18			
SDC-1-1										
DC-1			18							
NDC-7-1										
SDC-.5-2	91			145	18		18			
SDC-4-2	36			54		18				18
NDC-.5-2	91		18	344						36
SDC-2-2	36			145						
NDC-2-2	127			109	18	18	18			18
SDC-7-2	109			73						36
NDC-4-2										
SDC-.25-1	54	18		381		36				
NDC-1-2		18				18			18	
NDC-.25-1			18	54		54			91	163
DC-2	236		36	218		109				18
SDC-1-2	181	54	36	163		36			73	54
NDC-7-3	73	91	18			36	18		36	54
NDC-2-3	109	18		163		145			54	36
SDC-7-3	36	18		54		36			18	
NDC-.5-3	109	54		73		73			127	18
SDC-2-3	54		54	54		236			73	18
SDC-7-4						18				
NDC-7-4		18		54		36			54	18
DC-3	36					36			73	
SDC-.5-3		18		18		18			36	
SDC-4-3		91				109			127	145
NDC-4-3										18
NDC-1-3										
SDC-1-3	18			18		109			36	
DC-4		54		54		36			127	73
SDC-7-5						36			236	254
SDC-2-4						54			109	145
NDC-7-5		163				18	18		54	54
DC-5						36			18	
NDC-2-4								18	54	54
SDC-4-4				73						18
DC-6									54	18
NDC-4-4								54		18

TABLE 11 continued.

CHIRONOMIDAE, OLIGOCHAETA (with hair chaeta & unidentifiable in immature stages).

Station	Chironomidae						Tubificidae		
	<i>Mono tubr</i>	<i>Pott Long</i>	<i>Micr sp.2</i>	<i>Demi vuln</i>	<i>Conch sp.1</i>	<i>Para demj</i>	<i>Tubf tubf</i>	<i>Pelo supr</i>	imm.
NDC-2-1									
NDC-1-1									
SDC-2-1									
SDC-4-1		18							
SDC-7-1									
NDC-4-1									
NDC-.5-1									
SDC-.5-1					18				
SDC-1-1									
DC-1		18							
NDC-7-1									
SDC-.5-2	18	18		18					
SDC-4-2		36							
NDC-.5-2	54	18							18
SDC-2-2	18	18							
NDC-2-2									
SDC-7-2	36								
NDC-4-2									
SDC-.25-1	73	54							
NDC-1-2			18						
NDC-.25-1	471						290		725
DC-2	54	36		18					18
SDC-1-2	36	18					18		
NDC-7-3	18		18				18		18
NDC-2-3	18	18							36
SDC-7-3		18							
NDC-.5-3	36	18				18	18		18
SDC-2-3	36						18		109
SDC-7-4	36								
NDC-7-4	18								18
DC-3		18	18						36
SDC-.5-3	18								
SDC-4-3		36							18
NDC-4-3			18					18	18
NDC-1-3	36								
SDC-1-3									
DC-4	18	18					18		73
SDC-7-5	73								36
SDC-2-4	36		36						
NDC-7-5			145						
DC-5	18		18						
NDC-2-4	54	18	36				54		54
SDC-4-4									54
DC-6							91		1559
NDC-4-4							36		689

TABLE 11 continued.

OLIGOCHAETA (without hair chaetae & unidentifiable in immature stages).

Station	<i>Limn hoff</i>	<i>Limn cerv</i>	<i>Limn prof</i>	<i>Limn spir</i>	<i>Limn clap</i>	<i>Pota mold</i>	<i>Pota bedo</i>	<i>Pelo frey</i>	imm.
NDC-2-1									36
NDC-1-1									
SDC-2-1									163
SDC-4-1						18			
SDC-7-1						18			18
NDC-4-1									
NDC-.5-1									
SDC-.5-1						73			399
SDC-1-1									
DC-1									
NDC-7-1									
SDC-.5-2	36					54			888
SDC-4-2	18					18			236
NDC-.5-2	145			36		73			979
SDC-2-2	18		18			127			199
NDC-2-2						18		18	254
SDC-7-2				18		18			236
NDC-4-2									18
SDC-.25-1	18			18		18			816
NDC-1-2									18
NDC-.25-1	417	73	18	54		562			5113
DC-2	127	18				73			2194
SDC-1-2	181			18		199			2031
NDC-7-3	91								73
NDC-2-3	73		18						2502
SDC-7-3									145
NDC-.5-3						54			1197
SDC-2-3	109		18						2556
SDC-7-4									417
NDC-7-4						18			381
DC-3	54			36					344
SDC-.5-3									163
SDC-4-3	36					18		36	1360
NDC-4-3									218
NDC-1-3									490
SDC-1-3	91								2629
DC-4	362*		36	18	18	109		36	4877
SDC-7-5	54		54			18			3735
SDC-2-4	18					54			2031
NDC-7-5	91				18	36			1450
DC-5	18					18			381
NDC-2-4	236								4913
SDC-4-4	145					145		36	1632
DC-6	181			54		54	54		2284
NDC-4-4	218					326			2067

* One individual from sample DC 4 may have been *Limnodrilus maumeensis* or *Limnodrilus hoffmeisteri* with an irregular penal sheath head.

TABLE 11 continued.

OLIGOCHAETA (identifiable in immature stages).

Station	<i>Limm</i> <i>udek</i>	<i>Rhya</i> <i>cocc</i>	Tubificidae				Naididae		Lumbric. <i>Stylo herin</i>
			<i>Pota</i> <i>vejd</i>	<i>Pelo</i> <i>vari</i>	<i>Aulo</i> <i>plur</i>	<i>Aulo</i> <i>amer</i>	<i>Pigu</i> <i>mich</i>	<i>Unci</i> <i>unci</i>	
NDC-2-1									
NDC-1-1									
SDC-2-1									18
SDC-4-1									36
SDC-7-1									
NDC-4-1									
NDC-.5-1									
SDC-.5-1							18		18
SDC-1-1									
DC-1									
NDC-7-1									
SDC-.5-2							199	18	
SDC-4-2							109		36
NDC-.5-2					18				
SDC-2-2							36		
NDC-2-2							18		
SDC-7-2									
NDC-4-2									
SDC-.25-1									18
NDC-1-2									36
NDC-.25-1		36	91		435	18	18	18	199
DC-2			73						54
SDC-1-2		18	54				54		36
NDC-7-3					18				163
NDC-2-3			36						163
SDC-7-3									36
NDC-.5-3	18		18						73
SDC-2-3			54		54				326
SDC-7-4									18
NDC-7-4			18						254
DC-3									109
SDC-.5-3									54
SDC-4-3			36		36				1958
NDC-4-3			54			18			326
NDC-1-3									54
SDC-1-3			73		36				1650
DC-4			91						2973
SDC-7-5		54	363	18	18		18		5294
SDC-2-4			363						6726
NDC-7-5	36		54		18				2538
DC-5			54						5584
NDC-2-4	127								8159
SDC-4-4			689						4387
DC-6	326		91						3155
NDC-4-4	218	36							3282

TABLE 11 continued.

HIRUDINEA - PELECYPODA

Station	Hirudinea			Pisid spp.	Pelecypoda		
	<i>Helb</i> <i>stag</i>	<i>Glos</i> <i>comp</i>	Hirid sp.		<i>Sphr</i> <i>niti</i>	<i>Sphr</i> <i>stri</i>	<i>Sphr</i> <i>corn</i>
NDC-2-1							
NDC-1-1							
SDC-2-1							
SDC-4-1							
SDC-7-1							
NDC-4-1							
NDC-.5-1							
SFC-.5-1				36			
SDC-1-1							
DC-1							
NDC-7-1							
SDC-.5-2				18		36	
SDC-4-2				109	18		
NDC-.5-2				399		91	
SDC-2-2				91			
NDC-2-2				18			
SDC-7-2				36		36	
NDC-4-2							
SDC-.25-1				181		54	
NDC-1-2				181			
NDC-.25-1	54			616		109	
DC-2			18	399		109	
SDC-1-2	18			218	36		
NDC-7-3	163			344		73	109
NDC-2-3	18			326	18	18	
SDC-7-3	18			109			
NDC-.5-3	54			671	36	54	
SDC-2-3				653		163	
SDC-7-4				36			
NDC-7-4				91		18	
DC-3				73			
SDC-.5-3	36		18	91			
SDC-4-3	36			2266	471	73	
NDC-4-3	18			18			
NDC-1-3			18	145	91		
SDC-1-3			18	272	91	18	
DC-4	18	18		236	127		
SDC-7-5	109			1033	417	18	
SDC-2-4	54			2593	780		
NDC-7-5	36		18	163	218	18	
DC-5				363	18	18	
NDC-2-4				381	91	18	
SDC-4-4	18			2720	73		
DC-6				907			
NDC-4-4				1305		18	

TABLE 11 continued.

GASTROPODA - AMPHIPODA

Station	Gastropoda			Lymn spp.	Amphipoda		Mys rel
	<i>Valv sinc</i>	<i>Somt subg</i>	<i>Amni sp.</i>		<i>Ponto affin</i>	Total macro	
NDC-2-1						36	
NDC-1-1						0	
SDC-2-1						471	
SDC-4-1						344	
SDC-7-1						326	
NDC-4-1						18	
NDC-.5-1						0	
SDC-.5-1	18				18	1323	
SDC-1-1						0	
DC-1						36	
NDC-7-1						0	
SDC-.5-2	36				91	1702	
SDC-4-2	36				36	778	
NDC-.5-2	18	18	18		36	2410	
SDC-2-2	36	18			91	851	
NDC-2-2					54	688	
SDC-7-2					18	634	
NDC-4-2						36	
SDC-.25-1					109	1866	
NDC-1-2	54					325	
NDC-.25-1	109				36	9842	
DC-2	18				217	4043	
SDC-1-2					91	3623	
NDC-7-3	18					1450	
NDC-2-3	36				145	3950	
SDC-7-3					18	506	
NDC-.5-3	18				127	2882	
SDC-2-3					73	4658	
SDC-7-4					508	1033	
NDC-7-4	18				472	1486	
DC-3						833	
SDC-.5-3					127	597	
SDC-4-3	145			18	399	7414	
NDC-4-3					36	760	
NDC-1-3	36				181	1051	
SDC-1-3					653	5712	
DC-4	54				472	9916	
SDC-7-5	36			18	235	12127	
SDC-2-4	54			18	1161	14232	
NDC-7-5	36				1071	6253	
DC-5					4769	11313	
NDC-2-4					7252	21519	
SDC-4-4	18				1414	11422	18
DC-6					6456	15284	145
NDC-4-4					10787	19054	54

Key to abbreviations used for benthos species names in Table 11.

Chironomidae

Chironomus fluv
Chironomus anth
Chironomus tail

Cryptochir sp. 2
Cryptochir sp. 3
Paracladop obse
Paracladop roll
Heterotriess subp
Heterotriess grim
Proc sp.
Mono tubr
Pott long
Micr sp. 2
Demi vuln
Conch sp. 1
Para demj

Oligochaeta-Tubificidae

Tubf tubf
Pelo supr
imm.
Limn hoff
Limn cerv
Limn prof
Limn spir
Limn clap
Pota mold
Pota bedo
Pelo frey
Limn udek
Rhya coco
Pota vejd
Pelo vari
Aulo plur
Aulo amer

Oligochaeta-Naididae

Pigu mich
Unci unci

Oligochaeta-Lumbric

Stylo herin

Hirudinea

Helb stag
Glos comp
Hird sp.

Chironomidae

Chironomus fluviatilis group
Chironomus anthracinus group
tailless or otherwise unidentifiable

Cryptochironomus species 2
Cryptochironomus species 3
Paracladopelma cfr. obscura
Paracladopelma cfr. rolli
Heterotriessocladius cfr. subpilosus
Heterotriessocladius cfr. grimshawi
Procladius species unidentified
Monodiamesa tuberculata
Potthastia cfr. longimana
Micropsectra species 2
Demicryptochironomus cfr. vulneratus
Conchapelopia species 1
Parachironomus cfr. demejerei

Oligochaeta-Tubificidae

Tubifex tubifex
Peloscolex superiorenensis
immature
Limnodrilus hoffmeisteri
Limnodrilus cervix
Limnodrilus profundicola
Limnodrilus spiralis
Limnodrilus claparedianus
Potamothenis moldaviensis
Potamothenis bedoti
Peloscolex freyi
Limnodrilus udekemianus
Rhyacodrilus coccineus
Potamothenis vejdoskyi
Peloscolex variegatus
Aulodrilus plurisetus
Aulodrilus americanus

Oligochaeta-Naididae

Piguetella michiganensis
Uncinatus uncinatus

Oligochaeta-Lumbricidae

Stylodrilus heringianus

Hirudinea

Helobdella stagnalis
Glossiphonia complanata
Hirudinea species unidentified

Pelecypoda

Pisd spp.

Sphr niti

Sphr stri

Sphr corn

Gastropoda

Valv sinc

?*Somt subg*

Amni sp.

Lymn spp.

Amphipoda

Ponto affin

Mys rel

Pelecypoda

Pisidium spp.

Sphaerium nitidum

Sphaerium striatinum

Sphaerium corneum

Gastropoda

Valvata sincera

?*Somatogyrrus subglobosus*

Amnicola species unidentified

Lymnaea species unidentified

Amphipoda

Pontoporeia affinis

Mysis relicta

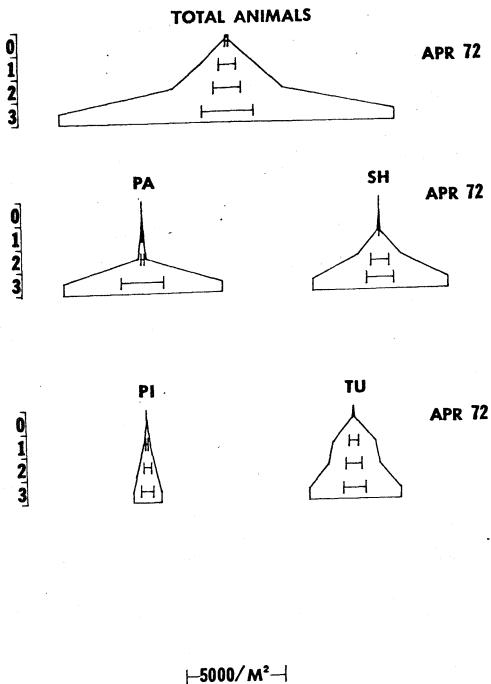
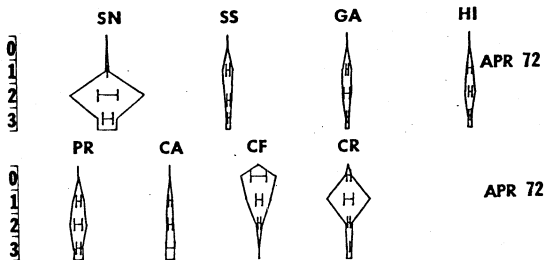
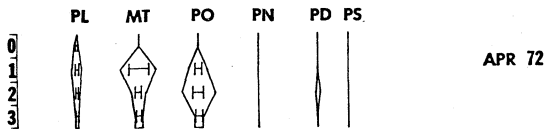


FIGURE 11. Means (diagram widths) and standard errors (inset brackets) by benthic depth zones (scales on left side) of the numbers of total animals and the more abundant taxa per square meter in the April 1972 grid survey. PA = *Pontoporeia affinis*, SH = *Stylodrilus heringianus*, PI = *Pisidium* spp., TU = Tubificidae.



— 500 / M² —



— 200 / M² —

FIGURE 12. Means (diagram widths) and standard errors (inset brackets) by benthic depth zones (scales on left side) of the numbers of several less abundant taxa in the April 1972 grid survey. SN = *Sphaerium nitidum*, SS = *S. striatinum*, GA = Gastropoda, HI = Hirudinea, PR = *Procladius*, CA = *Chironomus anthracinus*-group, CF = *C. fluviatilis*-group, CR = *Cryptochironomus* sp. 2, PL = *Potthastia* cfr. *longimanus*, MT = *Mono-dianesa tuberculata*, PO = *Paracladopelma* cfr. *obscura*, PN = *P. tylus*, PD = *Parachironomus* cfr. *demeijerei*, PS = *Polypedilum* cfr. *scalaenum*.

In spite of this relatively extensive list of new species names, the most outstanding generalization that can be made about this survey is that it showed very similar patterns of composition and depth distribution to that of the previous April.

The systematic-random surveys

At the end of 1973, five major zoobenthic surveys had been conducted according to the systematic-random design (Fig. 2): July and October 1972, and April, July and October 1973. The October 1973 survey has not yet been sorted. The April 1974 survey will be of this design, but then we will return to the radial grid (Fig. 1) unless events should indicate the necessity for additional, randomized surveys after the plant begins to operate continuously. The systematic-random survey was designed to describe two reference areas and the vicinity of the plant in maximum feasible statistical detail, without special regard to local spatial features within the region around the plant. It is not the best design for detecting localized effects of cooling water discharge because of its lack of stations in the areas of the lake defined along the beach by distances of between 1.6 and 8.0 km to both the north and the south of the plant, and because the locations of the sampling stations are re-randomized for each survey.

This report will provide a descriptive summary of data gathered so far, and point out differences in numbers of animals among zones, regions and months. The complete analysis of variance within and between regions is not ready for presentation, and will be covered in a later report.

The data are presented in a slightly summarized form in Tables 12 to 15. Means have been calculated for each station in the surveys for each taxon which is now being identified routinely without the use of compound micro-

TABLE 12. Station means and zone means and standard errors for macroscopically identifiable animals in the July 1972 major survey of benthic organisms. Units are numbers per square meter.

Stat.	Rep	Depth (m)	Pont.	Tabif.	Maid.	Stylo.	S. nit.	S. att.	Field.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total Animals
N01	5	7.3	4	0	0	0	0	0	0	747	12	0	0	0	763
N02	5	4.4	4	0	0	0	0	0	0	714	0	0	0	0	718
N03	5	7.3	65	457	45	4	0	8	12	600	0	0	0	0	1192
N-0(\bar{x})	3		25	152	15	1	0	3	4	687	4	0	0	0	891
(SE)			20	152	15	1		3	4	45	4				151
N11	3	15.1	444	324	222	0	0	0	0	242	0	0	0	0	1232
N12	3	10.8	404	3838	586	20	0	61	141	788	40	0	0	0	5878
N13	3	9.3	404	343	162	0	0	0	20	222	0	0	0	0	1151
N-1(\bar{x})	3		417	1502	323	7	0	20	54	417	14	0	0	0	2754
(SE)			13	1169	133	7		20	44	185	14				1364
N21	3	16.6	1939	61	121	0	0	0	20	121	0	0	0	0	2262
N22	3	20.4	727	121	40	20	61	0	0	162	20	0	0	0	1151
N23	3	17.5	2545	485	263	20	0	0	0	61	0	0	0	0	3374
N-2(\bar{x})	3		1737	222	142	14	20	0	7	115	7	0	0	0	2262
(SE)			535	133	65	7	20		7	30	7				643
N31	3	21.5	9029	2121	121	222	0	20	242	40	0	0	0	0	11796
N32	3	25.5	5414	4808	20	2828	828	20	2889	323	101	61	20	0	17312
N33	3	26.6	7636	2565	20	4707	323	20	1111	101	20	0	0	0	16504
N-3(\bar{x})	3		7360	3165	54	2586	384	20	1414	155	40	20	7	0	15204
(SE)			1034	832	34	1302	241	0	780	86	51	20	7		1722

TABLE 12 continued.

Stat.	Rep	Depth (m)	Ponto.	Tubif.	Mald.	Stylo.	S.nit.	S.str.	Plasid.	Chiro.	Hirud.	Oper.	Pula.	Other	Total Animals
D01	3	6.6	4	106	155	0	0	0	0	1771	4	0	0	0	2040
D02	5	7.4	16	208	237	0	0	0	20	3072	4	0	0	0	3558
D03	5	1.0	0	4	8	0	0	0	0	122	0	0	0	0	135
D-0(\bar{x})	3	7	7	106	133	0	0	0	7	1655	3	0	0	0	1911
(SE)			5	59	67				7	854	1				991
D11	3	14.6	404	121	323	0	0	20	61	364	0	0	0	0	1293
D12	3	13.8	1293	8040	343	20	0	242	303	3878	61	20	0	0	14199
D13	3	14.1	1737	2040	81	0	0	81	141	465	20	0	0	0	4565
D-1(\bar{x})	3	114.5	3400	249	7	7	0	114	168	1569	27	7	0	0	6686
(SE)		392	2388	84	7			67	71	1156	18	7			3878
D21	3	20.7	1495	8040	0	182	182	20	303	141	61	121	0	0	10545
D22	3	23.5	4060	8989	141	3353	283	20	2141	40	0	0	0	0	19028
D23	3	20.6	1333	101	343	0	20	0	0	40	0	0	0	0	1838
D-2(\bar{x})	3	2296	5710	161	1178	162	14	815	74	20	40	0	0	0	10470
(SE)		884	2821	99	1090	77	7	670	34	20	40				4963
D31	3	34.8	7757	8403	40	2788	20	0	2606	242	20	0	0	0	21877
D32	3	34.7	6222	12564	101	4161	61	0	2666	81	20	0	0	0	25876
D33	3	27.6	11171	5979	20	8504	162	0	6363	242	0	0	0	0	32441
D-3(\bar{x})	3	8383	8982	54	5151	81	81	0	3878	188	14	0	0	0	26731
(SE)		1464	1925	24	1725	42	42		1244	54	7				3083

TABLE 12 continued.

Stat.	Rep	Depth (m)	Pontic.	Fubif.	Wald.	Sylo.	S.nit.	S.str.	Flaid.	Chiro.	Hirud.	Oper.	Pula.	Other	Total Animals
S01	3	3.1	0	0	25	0	0	0	0	424	0	0	0	0	449
S02	3	6.3	16	812	53	0	0	8	12	665	0	8	0	0	1375
S03	3	7.0	16	1155	220	0	0	8	98	1652	0	12	0	4	3166
S-0(\bar{x})	3		11	656	99	0	0	5	37	914	0	7	0	1	1730
(SE)			5	343	61			3	31	376		4		1	789
S11	3	15.0	0	606	0	162	0	0	141	1818	0	0	0	0	2727
S12	3	12.5	808	2949	141	61	0	81	545	667	0	20	0	0	5292
S13	3	13.6	929	11292	545	20	0	101	848	3070	61	121	0	0	16987
S-1(\bar{x})	3		579	4949	229	81	0	61	511	1858	20	47	0	0	8335
(SE)			292	3247	164	42		31	205	689	20	38			4394
S21	3	19.0	2788	1596	242	424	20	20	323	61	20	0	0	0	5494
S22	3	20.7	5191	5292	40	889	747	61	869	81	202	20	0	0	13382
S23	3	21.1	3737	21048	141	384	505	222	1030	121	81	101	20	0	27390
S-2(\bar{x})	3		3905	9312	141	566	424	101	741	88	101	40	7	0	15425
(SE)			699	5971	58	162	214	62	214	18	54	31	7		6410
S31	3	22.9	6040	5373	0	3798	505	0	1596	101	182	0	0	0	17595
S32	3	24.8	3272	8888	303	2060	141	0	4305	0	61	20	0	0	18250
S33	3	30.3	3858	11130	40	5878	1010	20	5979	162	61	20	121	0	28279
S-3(\bar{x})	3		4390	8464	115	3912	552	7	4027	88	101	14	40	0	21708
(SE)			843	1677	95	1105	252	7	1289	47	41	7	40		3324

TABLE 13. Station means and zone means and standard errors for macroscopically identifiable animals in the October 1972 major survey of benthic organisms. Units are numbers per square meter.

Stat.	Map	Depth (m)	Ponto.	Tubif.	Naid.	Stylo.	G.nit.	G.str.	Flaid.	Chiro.	Hirud.	Opur.	Pulm.	Other	Total Animals
N04	5	4.3	0	8	20	0	0	0	0	33	0	0	0	4	65
N05	5	7.6	224	10069	490	8	0	57	249	506	4	0	0	20	11628
N06	5	8.8	49	498	575	37	0	0	45	159	4	0	0	4	1371
N-0(X)	3		91	3525	362	15	0	19	98	233	3	0	0	10	4355
(SE)			68	3279	173	11		19	77	142	1			5	3661
N14	3	16.5	2485	4282	141	505	141	0	970	404	20	81	0	20	9049
N15	3	12.2	343	5535	687	0	0	101	1394	182	40	20	0	0	8303
N16	3	16.5	1879	1414	81	586	141	20	990	182	0	61	61	20	5434
N-1(X)	3		1569	3744	303	364	94	40	1118	256	20	54	20	14	7595
(SE)			638	1221	193	184	47	31	138	74	12	18	20	7	1104
N24	3	25.6	5535	5070	0	2444	1071	0	6141	121	202	20	20	162	20786
N25	3	18.3	3535	485	566	222	0	40	202	222	0	0	61	20	5353
N26	3	20.1	4080	2868	162	1030	20	0	81	242	0	20	0	222	8725
N-2(X)	3		4383	2808	243	1232	364	14	2141	195	67	14	27	135	11621
(SE)			598	1325	169	650	354	14	2002	38	67	7	18	60	4690
N34	3	27.4	10201	2363	0	2828	81	0	3353	121	0	0	0	61	19007
N35	3	27.4	13231	1172	0	949	101	0	3616	20	0	0	0	141	19250
N36	3	29.3	12080	3899	20	3111	61	0	4222	162	40	20	0	40	23656
N-3(X)	3		11844	2478	7	2296	81	0	3730	101	14	7	0	81	20638
(SE)			890	790	7	679	12		258	42	14	7		31	1513

TABLE 13 continued.

Stat.	Rep	Depth	Fonco.	Tubif.	Naid.	Stylo.	S.nit.	S.str.	Pisid.	Chiro.	Hirud.	Opur.	Pulm.	Other	Total Animals
		(e)													
D04	5	6.1	12	286	286	0	0	12	45	796	16	4	0	4	1462
D05	5	9.1	277	3807	910	0	0	432	314	420	69	57	0	37	6323
D06	5	2.4	0	0	0	0	0	0	0	8	0	0	0	0	8
D-0(\bar{X})	3		97	1364	399	0	0	148	120	408	29	20	0	14	2598
(SE)			90	1225	269			142	98	228	21	19		12	4530
D14	3	11.0	222	141	242	0	0	0	101	162	40	0	0	20	929
D15	3	11.8	323	263	101	20	0	0	101	121	20	20	0	20	990
D16	3	7.9	222	4262	465	0	0	566	384	323	40	61	0	0	6323
D-1(\bar{X})	3		236	1355	269	7	0	189	195	202	34	27	0	14	2747
(SE)			34	1356	106	7		189	94	62	7	18		7	1790
D24	3	19.2	2283	4222	61	828	101	0	162	121	0	20	0	0	7798
D25	3	20.1	3575	6424	121	4363	1030	0	2384	81	242	20	20	0	18260
D26	3	20.1	3414	7535	0	5070	81	0	727	61	81	0	20	0	16988
D-2(\bar{X})	3		3091	6060	61	3420	404	0	1091	88	108	14	14	0	14349
(SE)			407	975	35	1314	313		668	18	71	7			3300
D34	3	23.8	13029	4989	0	6181	505	0	4040	40	0	20	40	0	28845
D35	3	25.6	2969	12928	20	2848	304	0	2929	141	20	40	0	0	22200
D36	3	27.4	6403	5171	20	4686	222	0	3434	61	0	0	0	0	19997
D-3(\bar{X})	3		7467	7696	14	4572	344	0	3468	81	7	20	14	0	23680
(SE)			2956	2620	7	965	84		321	31	7	12	14		2662

TABLE 13 continued.

Stat.	Rep	Depth	Ponto.	Tubif.	Naid.	Sydo.	G.nit.	S.salr.	Pisid.	Chiro.	Hirud.	Oper.	Pala.	Other	Total Animals
(s)															
S04	5	4.3	0	20	4	0	4	0	20	61	8	12	0	0	131
S05	5	5.3	12	118	359	0	8	12	41	379	4	25	0	4	962
S06	5	5.2	20	16	65	0	0	0	16	37	4	12	0	0	171
S-0(X)	3		11	52	143	0	4	4	26	139	5	16	0	1	421
(SE)			6	33	110		2	4	8	110	1	4		1	271
S14	3	12.5	283	444	667	0	0	0	121	101	20	20	0	20	1677
S15	3	15.9	747	1030	81	0	40	40	364	162	0	20	0	20	2505
S16	3	14.3	545	828	727	0	81	0	606	222	0	20	0	0	3029
S-1(X)	3		525	767	492	0	40	14	364	162	7	20	0	14	2404
(SE)			135	173	206		23	14	141	35	7	0		7	394
S24	3	19.2	4121	1838	81	1697	343	0	626	61	0	20	20	40	8847
S25	3	16.5	566	16281	20	162	162	0	4060	2808	40	61	0	81	24241
S26	3	25.6	7030	4464	0	5151	202	20	2060	81	0	0	20	0	19028
S-2(X)	3		3906	7228	34	2337	236	7	2249	983	14	27	14	40	17372
(SE)			1871	4447	24	1477	55	7	997	913	14	18	7	23	4526
S34	3	34.8	7211	5636	0	3919	20	0	2646	61	0	20	0	0	19513
S35	3	29.3	2505	4424	20	4446	81	0	2141	162	0	0	0	0	13979
S36	3	29.3	2121	4787	0	5555	61	0	2444	20	20	20	0	0	15028
S-3(X)	3		3946	4949	7	4707	54	0	2410	81	7	14	0	0	16173
(SE)			1638	380	7	474	18		147	42	7	7		7	1699

TABLE 14. Station means and zone means and standard errors for macroscopically identifiable animals in the April 1973 major survey of benthic organisms. Units are numbers per square meter.

Stat.	Rep	Depth (m)	Ponto.	Tubif.	Naid.	Stylo.	S.mit.	S.att.	Fisid.	Chiro.	Hirud.	Opat.	Pulm.	Other	Total Animals
N07	5	2.6	0	0	0	0	0	0	4	0	0	0	0	0	4
N08	5	6.8	41	53	0	0	0	0	12	16	4	0	0	0	127
N09	5	8.4	1325	1114	20	0	0	12	23	183	4	0	0	0	2682
N-0(Σ)	3		456	389	7	0	0	4	14	67	3	0	0	0	939
(SE)			435	362	7			4	6	59	1				874
N17	3	16.1	344	40	0	0	0	0	101	0	20	0	0	0	506
N18	3	14.9	364	304	20	0	0	0	20	61	0	0	0	0	769
N19	3	11.8	2384	2020	20	0	0	20	161	242	20	0	0	0	4848
N-1(Σ)	3		1024	787	14	0	0	7	94	101	14	0	0	0	2040
(SE)			670	621	7			6	41	73	7				1406
N27	3	18.0	8949	1091	0	161	0	61	586	404	0	61	0	0	11312
N28	3	19.2	9494	1212	0	202	0	20	465	262	0	0	0	40	11695
N29	3	18.0	4565	3151	40	141	61	40	1919	324	0	101	0	0	10342
N-2(Σ)	3		7669	1818	14	168	20	40	990	330	0	54	0	14	11117
(SE)			1560	668	14	18	20	12	466	41	29			14	403
N37	3	28.8	13898	4020	0	2606	40	0	7272	586	0	40	20	0	28483
N38	3	25.1	14322	4989	0	2909	182	0	3878	384	40	0	0	20	26723
N39	3	29.7	13110	3697	0	2060	0	0	5090	485	20	0	0	0	26462
N-3(Σ)	3		14443	4235	0	2525	74	0	5413	485	20	14	7	7	27222
(SE)			555	388		248	55		993	58	12	14	7	7	631

TABLE 14 continued.

Stat.	Rep	Depth	Ponto.	Tubif.	Naid.	Stylo.	S.mit.	S.str.	Pisid.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total Animals
(c)															
D07	5	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0
D08	5	10.8	2149	3645	14	7	0	320	272	320	61	95	0	0	6890
D09	5	4.6	0	0	0	0	0	0	0	41	0	0	0	0	41
D-0(X)	3		716	1215	5	2	0	107	93	120	20	32	0	0	2310
(SE)			716	1215	5	2		107	93	101	20	32			2290
D17	3	13.6	828	1697	20	20	0	0	182	61	20	0	0	0	2828
D18	3	13.6	1010	1071	20	0	0	40	606	283	20	0	0	0	3051
D19	3	16.7	747	2040	40	40	20	0	121	141	20	0	0	0	3170
D-1(X)	3		862	1603	27	20	7	14	303	162	20	0	0	0	3018
(SE)			78	283	7	12	7	14	153	65	0				100
D27	3	21.4	3495	13292	20	606	343	40	1636	667	40	61	0	182	20382
D28	3	22.0	1757	1212	0	101	20	0	323	81	0	0	0	20	3514
D29	3	19.5	2828	1111	20	61	141	0	323	141	0	20	0	20	4665
D-2(X)	3		2693	5205	14	256	168	14	761	296	14	27	0	74	9521
(SE)			506	4044	7	175	94	14	438	186	14	18		54	5441
D37	3	25.1	2767	13211	20	2464	202	0	7171	323	40	40	0	20	26259
D38	3	26.3	11514	9918	0	5939	343	20	7494	808	20	121	0	20	36198
D39	3	29.4	3495	12080	0	3131	283	0	7353	263	0	61	0	0	26666
D-3(X)	3		5925	11736	7	3845	276	7	7339	465	20	74	0	14	29707
(SE)			2802	966	7	1064	41	7	94	173	12	24		7	3244

TABLE 14 continued.

Stat.	Rep	Depth	Ponto.	Tubif.	Naid.	Stylo.	S.mit.	S.attr.	Pisid.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total	Animals
(a)																
S07	5	4.6	0	16	0	0	0	0	16	224	4	0	0	0	261	
S08	5	7.0	49	2101	0	4	0	16	20	310	4	0	0	0	2505	
S09	5	3.7	0	10	0	0	0	0	0	20	0	0	0	0	31	
S-0(X)	3		16	709	0	1	0	5	12	185	3	0	0	0	932	
(SE)			16	696		1		5	6	86	1				789	
S17	3	16.8	3192	51490	3030	0	20	0	2101	1355	40	20	0	121	61570	
S18	3	14.9	1212	5656	61	0	0	20	182	424	20	0	0	0	7575	
S19	3	18.0	2242	707	0	20	0	0	162	162	20	0	0	0	3313	
S-1(X)	3		2215	19284	1030	7	7	7	815	714	27	7	0	40	24153	
(SE)			572	16166	1000	7	7	7	643	427	7	7		40	18749	
S27	3	21.0	3333	7252	0	1818	242	40	1697	364	0	101	0	20	14868	
S28	3	19.5	5131	20725	0	586	424	81	3777	788	182	323	0	687	32704	
S29	3	20.4	7939	9272	40	2081	626	81	4080	465	20	202	0	0	24807	
S-2(X)	3		5468	12416	14	1495	431	67	3185	539	67	209	0	236	24127	
(SE)			1340	4195	14	461	111	14	749	128	58	64		226	5160	
S37	3	29.6	1939	12463	121	5818	323	0	8666	121	0	40	0	40	29532	
S38	3	28.4	1556	18220	81	3070	384	0	18725	343	40	121	0	20	42600	
S39	3	30.5	3737	7535	20	3858	182	0	8080	263	0	0	0	20	23695	
S-3(X)	3		2424	12739	74	4249	296	0	11824	242	14	54	0	27	31942	
(SE)			664	3088	29	817	60		3455	65	14	36		7	5589	

TABLE 15. Station means and zone means and standard errors for macroscopically identifiable animals in the July 1973 major survey of benthic organisms. Units are numbers per square meter.

Stat.	Rep	Depth	Ponto.	Tubif.	Naid.	Stylo.	S.nit.	S.str.	Pisid.	Chtro.	Hirud.	Opas.	Pula.	Other	Total Animals
(x)															
N010	5	5.5	0	4	763	0	0	0	0	755	0	0	0	0	1522
N011	5	7.9	94	641	2036	8	0	0	33	951	8	0	0	12	3783
N012	5	6.7	20	135	3554	0	0	0	0	641	4	0	0	4	4359
N-0(x)	3		38	260	2118	3	0	0	11	782	4	0	0	5	3221
(SE)			29	195	807	3			11	91	2				865
N110	3	13.7	2968	121	545	121	0	0	20	444	20	0	0	81	4321
N111	3	12.8	3232	1819	606	162	0	0	20	1172	0	20	0	323	7454
N112	3	12.2	7817	2565	687	485	121	40	1454	2283	0	40	0	727	16220
N-1(x)	3		4673	1535	613	256	40	14	498	1300	7	20	0	377	9332
(SE)			1574	731	41	116	40	14	478	534	7	12		188	3561
N210	3	23.5	7070	7333	40	5999	747	0	5818	101	40	242	0	40	27431
N211	3	18.3	8363	788	586	283	0	0	101	81	40	0	0	182	10444
N212	3	24.4	15958	1838	0	7312	263	0	6060	61	20	40	20	20	31593
N-2(x)	3		10470	3320	209	4531	337	0	3993	81	34	94	7	81	23156
(SE)			2770	2029	189	2158	219		1947	12	7	75	7	51	6469
N310	3	35.1	14079	12039	0	6201	0	0	4808	0	0	0	0	0	37127
N311	3	28.7	16887	7413	20	5878	20	0	7353	121	0	0	0	0	37692
N312	3	27.1	15029	4949	0	4666	101	0	6201	61	0	0	0	0	31007
N-3(x)	3		15332	8134	7	5582	40	0	6121	61	0	0	0	0	35277
(SE)			825	2078	7	467	31		735	35					2140

TABLE 15 continued.

Stat.	Exp	Depth	Fonto.	Tubif.	Naid.	Styls.	S.nit.	S.attr.	Fisid.	Chfro.	Hfrod.	Oper.	Pulm.	Other	Total Animals
(a)															
D010	5	0.9	4	0	12	0	0	0	0	0	57	0	0	0	73
D011	5	6.7	4	253	2978	0	0	0	0	4802	53	4	0	0	8155
D012	5	3.4	0	0	155	0	0	0	0	926	0	0	0	0	1097
D-0(Σ)	3		3	84	1048	0	0	0	0	1928	18	1	0	26	3108
(SE)			1	84	966					1459	18	1		18	2541
D110	3	13.7	5838	1697	1192	61	61	20	182	1454	0	20	0	404	10929
D111	3	15.2	1757	26927	282	283	40	61	1192	485	121	40	0	81	31269
D112	3	13.1	6605	5898	747	81	121	40	1050	1373	81	20		646	16662
D-1(Σ)	3		4733	11507	740	141	74	40	808	1104	67	27	0	377	19619
(SE)			1505	7804	262	71	24	12	316	311	36	7		164	6055
D210	3	18.6	7434	10504	444	3575	1394	61	4323	424	20	81	20	81	28361
D211	3	18.0	6605	9796	242	2929	263	40	1071	182	20	81	0	182	21351
D212	3	18.3	6444	11676	444	2990	40	0	2242	465	0	202	61	121	24685
D-2(Σ)	3		6828	10639	377	3165	566	34	2545	357	14	121	27	128	24800
(SE)			307	564	67	206	419	18	951	88	6	40	18	29	2024
D310	3	30.8	12181	6242	0	6585	0	0	6525	40	0	40	0	0	31614
D311	3	35.7	12867	11433	20	5171	0	0	4444	20	0	0	0	0	33955
D312	3	34.1	13918	9656	0	6626	0	0	6121	40	0	0	0	0	36360
D-3(Σ)	3		12989	9110	7	6127	0	0	5697	34	0	14	0	0	33977
(SE)			505	1323	7	478			637	7					1370

TABLE 15 continued.

Stat.	Rep	Depth	Femur	Tubif.	Wid.	Stylo.	S. Ant.	S. Str.	Platid.	Chiro.	Hirud.	Oper.	Pulm.	Other	Total	Animals
(a)																
S010	5	8.5	437	1571	2632	8	33	25	245	1248	167	29	0	180	6594	
S011	5	6.4	57	547	714	0	0	0	57	3966	12	8	0	37	5398	
S012	5	6.1	45	983	636	8	4	25	53	3468	16	16	0	29	5283	
S-0(7)	3		180	1034	1334	5	12	16	118	2894	65	18	0	82	5759	
(SE)			129	297	659	3	10	8	64	835	51	6		49	419	
S110	3	16.8	6626	4444	586	303	0	0	566	1394	0	81	0	242	14442	
S111	3	14.0	2525	66862	525	121	202	40	2283	1675	40	40	0	182	74295	
S112	3	15.2	3434	8383	606	20	40	0	586	667	0	0	0	61	13797	
S-1(7)	3		4195	26563	572	148	81	14	1145	1179	14	40	0	162	34112	
(SE)			1243	20183	24	83	62	14	369	257	14	23		53	20092	
S210	3	23.8	2889	17291	0	4020	343	0	3757	202	0	0	20	20	28342	
S211	3	16.8	10524	1959	202	1980	162	0	182	364	0	40	0	182	15595	
S212	3	15.6	6727	3010	242	162	121	0	404	323	20	61	0	263	11333	
S-2(7)	3		6713	7420	148	2054	209	0	1447	296	7	34	7	155	18489	
(SE)			2204	4945	75	1114	69		1156	49	7	18	7	71	5174	
S310	3	35.4	13251	7939	0	4909	20	0	3636	121	0	0	0	0	29876	
S311	3	29.0	9131	6121	0	6343	0	0	7151	20	0	0	0	0	28786	
S312	3	31.7	11453	7575	0	5030	20	0	5858	0	0	20	0	0	29956	
S-3(7)	3		11285	7212	0	5427	14	0	5548	47	0	7	0	0	29539	
(SE)			1187	555		458	7		1026	37		7		898		

scopes. The station means have been used as the basis for calculating the corresponding zone means and standard errors ($n=3$) which are presented below each zonal set of 3 stations.

The data for zone 0 were subject to vagaries in station location. The depth contours were not exactly parallel to the beach, and the approximation of the location of the 8-m contour which defined the area of randomization was not always accurate. As a result, the depths of stations which fell near the outer edge of zone 0 were often more than 8 m deep. This was usually reflected in abnormally large numbers of zoobenthos at those stations relative to others in zone 0. Depths are given in Tables 12-15 beside each station.

The data in Tables 12-15 have been used to draw "kite" diagrams which simultaneously illustrate distribution according to depth zones, regions and months for each taxon (Figs. 13 to 21). These are structured so that the width of the diagrams at the center of each benthic depth zone (marked at the margin) is proportional to the number of animals per m^2 . The scale of width changes from figure to figure and is shown as an inset at the bottom of each. At the level of the zone centers, one standard error of the mean (same as in Tables 12 to 15) is shown as a horizontal bar. The scale of the standard error bars is the same as for the means (width of the diagrams). The north (N) and south (S) reference transects, or regions, and the Cook area region (D) are labelled above each column of diagrams.

Numbers of total animals (Fig. 13) were generally less variable in the north and Cook regions than in the south region. In April and July 1973, both mean numbers per m^2 and standard errors were very large in the south region in zone 1. Standard errors were always smaller in relation to the mean in zone 3 than in shallower zones. With two exceptions, zone 3 had the largest mean, and zone 0 always had the smallest mean, of any zone in a given month.

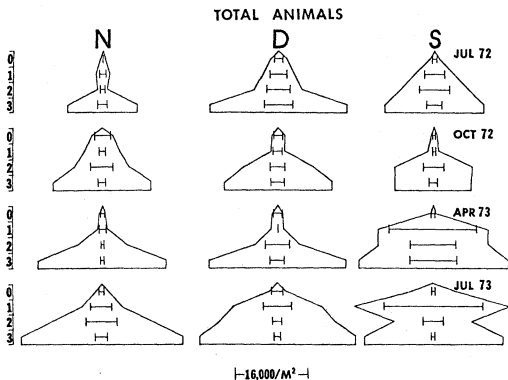


FIGURE 13. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for total animals in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

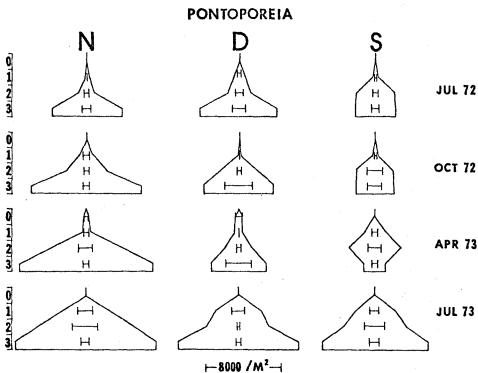


FIGURE 14. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for *Pontoporeia affinis* in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

TUBIFICIDAE (total)

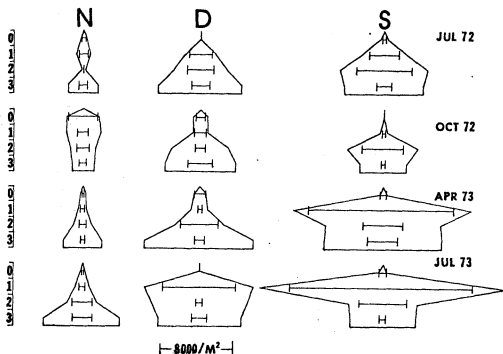


FIGURE 15. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for Tubificidae in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

STYLODRILUS

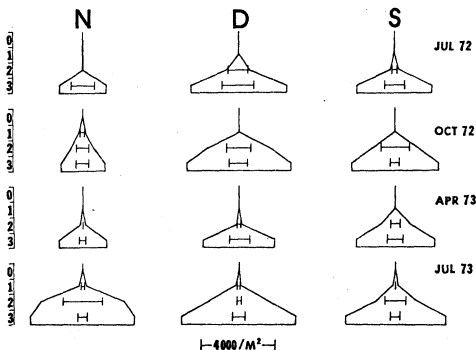


FIGURE 16. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for Stylodrilus heringianus in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

PISIDIUM SPP.

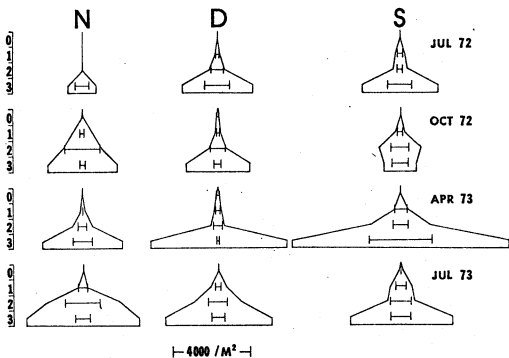


FIGURE 17. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for *Pisidium* spp. in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

S. NITIDUM

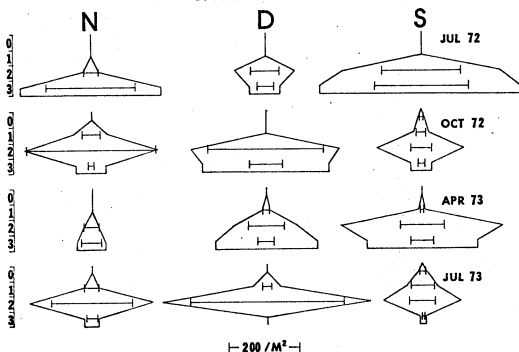


FIGURE 18. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for *Sphaerium nitidum* in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

CHIRONOMIDAE (total)

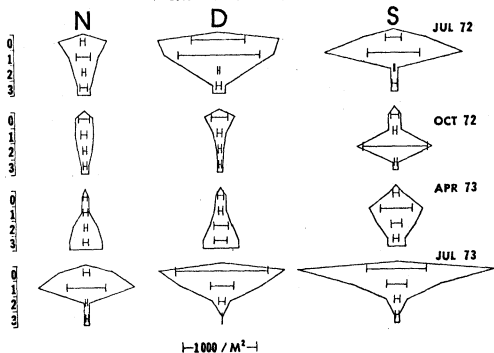


FIGURE 19. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for Chironomidae in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

NAIDIDAE

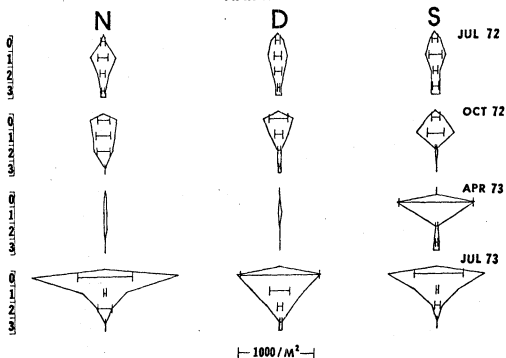


FIGURE 20. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for Naididae in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

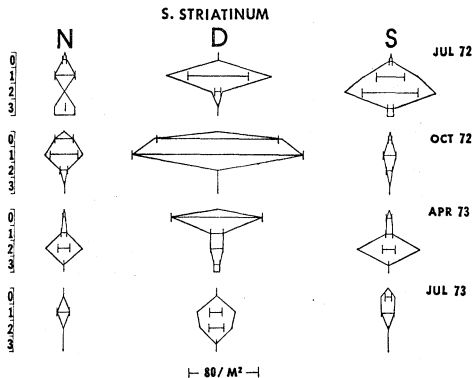


FIGURE 21. Means (diagram widths) and standard errors (inset brackets) by benthic depth zone (scales on left side) for *Sphaerium striatinum* in the first four systematic-random surveys. N = north reference, D = Cook Plant region, S = south reference.

Zone 1 and 2 means were highly variable between regions in each month and between months for the same region.

Pontoporeia affinis (Fig. 14) was usually the most abundant single species in the survey area (see earlier reports) but was never as much as 50% of total animals in the south and Cook regions. This amphipod was almost always most abundant in the north region and least abundant in the south region. The coefficient of variation tended to decrease with increasing depth, especially in the north region. Data from zone 1 in July 1973 show larger means for *Pontoporeia* than had been recorded in previous Julys. A more detailed discussion of seasonal variations and reproduction may be found in the section on seasonality of *Pontoporeia* size distribution. *Pontoporeia* was absent or rare in zone 0.

Total Tubificidae (Fig. 15) showed approximately reverse tendencies in relative regional abundance. In the south and Cook regions, means of Total Tubificidae were close to 50% of total animals in zone 2, but in the north region they were much less numerous proportionally as well as absolutely. Tubificidae was the dominant taxon in contribution to the large means and standard errors of total animals in zone S-1 in April and July 1973 and in zone D-1 July 1973. Tubificidae were normally rare in zone 0.

Stylodrilus heringianus (Fig. 16) seemed to be less abundant in the north region than in the Cook and south regions until July 1973. *Stylainilus* was essentially absent from zone 0 and very rare in zone 1 in all regions. In zone 2 this species varied about as much from survey to survey as among regions.

Pisidium (several species combined, Fig. 17) showed little in the way of patterns of abundance. This genus was absent or rare in zone 0 and often rare in zone 1. With one exception, the largest means fell in zone 3. The

standard-error-to-mean ratios were usually lowest in zone 3. The numbers of *Pisidium* increased dramatically in zone 3 of the south and Cook regions in April 1973 and the following July survey indicated larger means than did the July 1972 survey. This April maximum was not observed in the April 1972 survey (Fig. 11).

Sphaerium nitidum (Fig. 18) was originally presented as the typical species of zone 2 (Mozley 1973a). It often exhibited higher means in zone 3, however, and its numbers were so variable (note large standard errors) that it would be difficult to make any quantitative generalization from the relatively small number of samples on which these figures are based. Variability within each zone was apparently as large as or larger than variability between zones 2 and 3 or among the regions. *S. nitidum* was always rarer in zones 0 and 1 than in zone 2.

Total Chironomidae (Fig. 19) were seasonally regular in abundance. July in both 1972 and 1973 was the month of maximum abundance (see also Fig. 12) in zones 0 and 1. In zones 2 and 3 however, there were generally more larvae in April 1973 collections. The quantities of Chironomidae larvae were greater in the Cook and south regions than in the north region. Although Chironomidae had the smallest standard error to mean ratios in the grab comparison study (see Tables 5 and 6) the ratios were not particularly small over the various zones. Except during the July maximum, there was no regular pattern in the depth distribution of numbers of chironomid larvae, but their proportion in total animals was always largest in zone 0.

Naididae (Fig. 20) were rare in zone 3 and relatively less abundant in zone 2 than in shallower zones. In July 1973 (and in the south region in April 1973), there were large Naididae populations in zones 0 and 1. It is very unlikely that such explosions would have been completely missed in previous

summers. This was one of the most dramatic examples of year-to-year changes in zoobenthos at the Cook Plant. There were no indications that one region had consistently more or less Naididae than another.

The last figure in this series (Fig. 21) shows the quantities of *Sphaerium striatinum* found in the surveys. This species was rare in numbers but relatively large in size (mature specimens usually over 1 cm long) and it would appear more important if data were reported by biomass. The figure calls attention to the tendency for this species to be more abundant in the Cook region (zones 0 and 1) than in either the north or south regions. This is the only taxon for which such a tendency has been noted. Standard errors often approached or equaled the mean, as for *S. nitidum* (Fig. 18) so that the differences apparent in the figure may be deceptive.

The other taxa listed in the corresponding tables were relatively rare and showed no particular regional or seasonal patterns of abundance. In the interest of economy of space, further illustrative figures have been omitted from this report.

The short surveys and seasonal fluctuations

Beginning in May 1972, a set of 9 stations was sampled in the months between April and November when major surveys were not conducted. They were stations of the systematic grid (Fig. 1), mostly along the D transect with the addition of a station (DC-0) near the entrance to a temporary safe harbor which was installed during construction of the plant. Stations SDC-.5-1 and NDC-.5-1 provided additional information about the zoobenthos at depths less than 8 m, and gave continuity when intake pipes and riprap were installed over station DC-1. The purpose in sampling these stations was to be able to detect seasonal events which occurred in months other than major survey months. No

collection was obtained in November 1973, due to bad weather and ship scheduling difficulties.

The data for short surveys are given as means and standard errors for each station and survey, and for most taxa identifiable without the compound microscope (Tables 16-24). The short surveys of May and June 1972 have already been listed (Mozley 1973a) but additional taxonomic detail is given in Tables 16 and 17. The *Sphaerium* species and types of Gastropoda were not distinguished by oversight when some samples were sorted (Table 19), and we have been unable to locate some of the preserved replicates from stations for which those distinctions were omitted.

The month-to-month mean numbers in major zoobenthic taxa have been drawn from these tables and from the Cook region (D) in Tables 12 to 15, and combined with grid data from the central part of the survey area in July 1970 to April 1972 (Mozley and Garcia 1972; Mozley 1973b, 1974; and Table 11 above) to cover the entire span of the Cook Plant benthos surveys. The stations of the D region from each survey were combined by depth into the four benthic zones and converted to numbers per m², then means and standard errors were calculated when possible (some grid surveys yielded only one observation in benthic zones D 2 or D 3). The resulting means were plotted against month and year by depth zones for the more abundant taxa (Figs. 22-28). The figure in this series for *Pontoporeia* has been placed in a separate section titled "Seasonality of *Pontoporeia* size distribution."

Total animals (Fig. 22) were most abundant in summer and fall in each depth zone. This seasonality was more pronounced in the three shallower zones. The monthly survey with the most animals varied from year to year and zone to zone. Each zone had higher numbers of total animals than the next shallower, and fewer than the next deeper zone, except on three occasions in

TABLE 16. Station means and standard errors for macroscopically identifiable animals in May 1972 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	DC-1	SDC 5-1	SDC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Pentaceroidea	0	0	0	0	184 ± 47	0	61 ± 12	6344 ± 456	6446 ± 147
Tubificidae	0	0	0	0	2781 ± 476	626 ± 298	190 ± 45	3399 ± 944	3359 ± 404
Naididae	0	0	0	0	34 ± 18	0	0	0	0
Stylocerium	0	0	0	0	143 ± 85	143 ± 143	75 ± 18	6384 ± 643	3550 ± 312
Spil. nitidum	0	0	0	0	41 ± 0	34 ± 34	75 ± 18	177 ± 48	7 ± 7
Spil. nitidum	0	0	0	0	75 ± 34	48 ± 48	0	150 ± 53	1210 ± 147
Chironomidae	0	0	0	0	457 ± 184	468 ± 468	125 ± 30	170 ± 23	218 ± 25
Hirudinea	0	7 ± 7	41 ± 12	75 ± 30	537 ± 113	626 ± 546	75 ± 7	7 ± 7	7 ± 7
Operculata	0	0	0	0	102 ± 41	27 ± 7	14 ± 7	0	7 ± 7
Pulmonata	0	0	0	0	34 ± 14	0	95 ± 60	14 ± 14	0
other	0	0	0	0	0	0	0	0	0
Total Animals	0	14 ± 7	41 ± 12	75 ± 30	4400 ± 601	2000 ± 1516	741 ± 248	17054 ± 3876	15055 ± 703

TABLE 17. Station means and standard errors for macroscopically identifiable animals in June 1972 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	DC-1	SDC 5-1	SDC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Pentaceroidea	14 ± 14	20 ± 12	0	14 ± 14	3309 ± 543	892 ± 609	2737 ± 720	5164 ± 1675	7507 ± 531
Tubificidae	0	14 ± 14	0	0	3203 ± 1451	265 ± 245	7689 ± 909	884 ± 347	5204 ± 1020
Naididae	0	0	0	0	75 ± 34	7 ± 7	537 ± 527	7 ± 7	327 ± 118
Stylocerium	0	7 ± 7	0	0	48 ± 38	48 ± 48	1013 ± 746	4576 ± 1343	3808 ± 519
Spil. nitidum	0	0	0	0	82 ± 12	0	422 ± 137	7 ± 7	20 ± 12
Spil. nitidum	0	7 ± 7	0	0	61 ± 12	34 ± 7	320 ± 20	420 ± 31	0
Chironomidae	0	7 ± 7	0	0	157 ± 12	61 ± 31	490 ± 235	158 ± 7	300 ± 1144
Hirudinea	7 ± 7	190 ± 48	184 ± 184	592 ± 54	54 ± 25	7 ± 7	34 ± 25	48 ± 18	14 ± 14
Operculata	0	0	0	0	88 ± 36	7 ± 7	68 ± 58	14 ± 7	7 ± 7
Pulmonata	0	0	0	0	7 ± 7	0	7 ± 7	0	0
other	0	0	0	0	0	0	0	0	0
Total Animals	20 ± 20	258 ± 60	184 ± 184	606 ± 41	7870 ± 2158	1231 ± 936	9350 ± 1863	11281 ± 3573	19726 ± 3239

TABLE 18. Station means and standard errors for macroscopically identifiable animals in August 1972 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SIG. 5-1	WOC. 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Pontoporeia	0	27 ± 14	0	2563 ± 617	1537 ± 339	2727 ± 1003	11009 ± 1447	10404 ± 896
Tubificidae	0	27 ± 18	130 ± 109	3380 ± 551	585 ± 237	2530 ± 809	3067 ± 1048	6814 ± 1364
Naididae	0	41 ± 31	537 ± 275	156 ± 95	95 ± 14	156 ± 90	14 ± 14	7 ± 7
Syllodrilus	0	0	0	27 ± 14	7 ± 7	605 ± 250	1775 ± 96	2081 ± 305
Sph. nitidum	0	0	0	129 ± 92	16 ± 14	83 ± 95	34 ± 34	0
Sph. striatum	0	0	0	0	0	0	0	0
Pisidium spp.	0	14 ± 14	0	415 ± 159	75 ± 55	850 ± 700	415 ± 195	2292 ± 1837
Cirronomidae	20 ± 12	435 ± 68	306 ± 105	721 ± 366	340 ± 118	116 ± 25	27 ± 18	7 ± 7
Hirudinea	0	14 ± 7	0	204 ± 185	0	102 ± 61	0	0
Operculata	0	0	0	0	0	143 ± 62	7 ± 7	0
Alumina	0	7 ± 7	0	0	0	0	0	0
Other	0	0	0	0	27 ± 27	20 ± 20	0	0
Total Animals	20 ± 12	565 ± 59	993 ± 304	7670 ± 1080	2886 ± 696	8168 ± 2850	16402 ± 592	21604 ± 3769

TABLE 19. Station means and standard errors for macroscopically identifiable animals in September 1972 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SIG. 5-1	WOC. 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Pontoporeia	7 ± 7	0	7 ± 7	429 ± 316	1034 ± 353	3958 ± 904	9024 ± 642	11744 ± 2367
Tubificidae	0	0	34 ± 25	4641 ± 2923	2836 ± 1303	8555 ± 854	2142 ± 182	5767 ± 1267
Naididae	0	0	0	82 ± 17	197 ± 126	14 ± 14	48 ± 14	14 ± 14
Syllodrilus	0	0	0	0	4 ± 31	84 ± 31	420 ± 187	3414 ± 417
Sph. nitidum	14 ± 14	14 ± 14	0	0	0	646 ± 169	122 ± 77	7 ± 7
Sph. striatum	0	0	0	14 ± 14	14 ± 14	0	7 ± 7	3162 ± 1461
Pisidium spp.	0	0	704 ± 684	224 ± 116	1285 ± 160	1754 ± 614	18 ± 18	0
Cirronomidae	0	340 ± 107	408 ± 85	1530 ± 1166	272 ± 191	102 ± 42	88 ± 18	0
Hirudinea	0	0	102 ± 67	61 ± 51	95 ± 67	20 ± 12	0	0
Operculata	0	0	0	0	0	14 ± 14	14 ± 14	0
Alumina	7 ± 7	0	0	41 ± 33	7 ± 7	14 ± 14	14 ± 7	0
Polychaeta	0	0	0	0	0	14 ± 14	82 ± 82	0
Other	35 ± 25	0	20 ± 0	0	0	0	0	0
Total Animals	82 ± 41	353 ± 95	456 ± 120	7548 ± 5453	4685 ± 1526	13280 ± 1590	17509 ± 2595	24101 ± 5303

TABLE 20. Station means and standard errors for macroscopically identifiable animals in November 1972 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SPC 5-1	NBC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Pontoporeia	0	48 ± 30	14 ± 7	52 ± 108	599 ± 123	3488 ± 284	9670 ± 429	10159 ± 225
Tubificidae	0	135 ± 108	108 ± 108	112 ± 108	112 ± 108	668 ± 108	1066 ± 145	630 ± 488
Naididae	0	612 ± 183	55 ± 27	150 ± 55	20 ± 12	12 ± 0	0	0
Stylodrilus	0	14 ± 14	7 ± 7	7 ± 7	422 ± 100	4080 ± 259	6766 ± 462	3971 ± 380
Sph. nitidum	0	0	0	48 ± 7	27 ± 14	680 ± 107	259 ± 146	0
Sph. striatum	0	7 ± 7	0	27 ± 7	0	0	0	0
Sph. striatum spp.	0	0	0	387 ± 43	14 ± 14	925 ± 321	2802 ± 1118	2509 ± 282
Chironomidae	0	666 ± 206	90 ± 143	181 ± 94	483 ± 7	251 ± 30	224 ± 83	143 ± 47
Glyptotendipes	0	0	0	34 ± 7	0	41 ± 35	14 ± 7	0
Hirudinea	0	0	0	0	0	0	0	0
Opereculata	0	0	0	14 ± 14	0	20 ± 12	0	0
Palaemonia	0	0	14 ± 7	0	0	0	0	0
other	0	0	0	0	0	0	0	0
Total Animals	0	135 ± 348	1088 ± 143	2904 ± 477	2448 ± 744	16246 ± 712	20781 ± 1907	23113 ± 176

TABLE 21. Station means and standard errors for macroscopically identifiable animals in May 1973 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SPC 5-1	NBC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Pontoporeia	0	20 ± 20	242 ± 121	4181 ± 804	6504 ± 2263	4000 ± 819	7716 ± 1746	10382 ± 1071
Tubificidae	0	0	0	3575 ± 2167	34805 ± 13208	1414 ± 767	1717 ± 901	6121 ± 1031
Naididae	0	0	0	40 ± 40	0	0	20 ± 20	0
Stylodrilus	0	0	0	40 ± 40	144 ± 313	50 ± 430	1677 ± 688	3310 ± 284
Sph. nitidum	0	0	0	40 ± 20	283 ± 20	0	140 ± 88	0
Sph. striatum	0	0	0	20 ± 20	61 ± 35	0	0	0
Sph. striatum spp.	0	0	0	81 ± 81	3030 ± 1123	181 ± 0	2081 ± 544	4161 ± 280
Chironomidae	0	40 ± 40	101 ± 20	404 ± 81	1313 ± 466	202 ± 113	61 ± 35	343 ± 40
Drepanidae	0	0	0	141 ± 141	40 ± 20	0	0	0
Opereculata	0	0	0	20 ± 20	0	0	0	0
Palaemonia	0	0	0	0	0	0	0	0
other	0	0	0	0	0	0	0	0
Total Animals	0	61 ± 61	343 ± 113	8543 ± 2595	47531 ± 12108	6342 ± 1939	13595 ± 2159	24220 ± 1504

TABLE 22. Station means and standard errors for macroscopically identifiable animals in June 1973 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SDC 5-1	NDC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Polychaeta	0	61 ± 0	20 ± 20	2484 ± 455	970 ± 494	5898 ± 841	10444 ± 3396	10060 ± 370
Caprellidae	0	0	0	1273 ± 504	3186 ± 10819	13271 ± 769	1555 ± 1073	4020 ± 775
Amphipoda	0	80 ± 42	40 ± 40	0	1172 ± 62	1434 ± 531	2325 ± 787	3532 ± 739
Stomatopoda	0	0	0	0	151 ± 88	545 ± 229	727 ± 555	0
Sph. nitidum	0	0	0	20 ± 20	35 ± 35	0	0	0
Sph. striatum	0	0	0	181 ± 35	61 ± 35	0	0	0
Pisidium spp.	0	40 ± 31	20 ± 20	242 ± 70	1010 ± 547	2323 ± 1013	7494 ± 2963	3959 ± 158
Chironomidae	188 ± 50	606 ± 334	485 ± 93	162 ± 20	202 ± 88	444 ± 202	40 ± 20	343 ± 141
Hydratula	0	0	0	0	384 ± 297	222 ± 141	40 ± 20	20 ± 20
Corbicula	0	0	0	54 ± 20	40 ± 20	20 ± 20	20 ± 20	0
Palaemonetes	0	0	0	0	0	0	0	0
other	0	0	0	0	202 ± 123	20 ± 20	0	0
Total Animals	188 ± 50	808 ± 386	626 ± 107	4806 ± 1115	36179 ± 22599	24420 ± 9564	22966 ± 7757	21634 ± 1310

TABLE 23. Station means and standard errors for macroscopically identifiable animals in August 1973 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SDC 5-1	NDC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Polychaeta	4 ± 4	970 ± 253	101 ± 20	889 ± 628	4323 ± 193	5212 ± 555	7090 ± 1851	10524 ± 905
Caprellidae	0	163 ± 93	0 ± 20	614 ± 407	424 ± 112	3474 ± 58	1313 ± 391	4666 ± 61
Amphipoda	0	263 ± 22	22 ± 34	1446 ± 374	742 ± 112	1420 ± 21	4323 ± 1020	2363 ± 398
Stomatopoda	0	20 ± 20	0	141 ± 81	81 ± 47	2980 ± 1180	4323 ± 1020	2363 ± 398
Sph. nitidum	0	20 ± 20	0	182 ± 93	0	162 ± 54	202 ± 145	0
Sph. striatum	0	61 ± 61	0	121 ± 70	101 ± 40	0	0	0
Pisidium spp.	0	626 ± 193	0	869 ± 462	949 ± 233	3676 ± 228	3676 ± 636	1980 ± 820
Chironomidae	0	242 ± 124	1818 ± 364	404 ± 245	343 ± 112	81 ± 20	81 ± 20	20 ± 20
Hydratula	0	101 ± 73	0	81 ± 40	0	40 ± 40	20 ± 20	20 ± 20
Corbicula	0	0	0	0	0	0	0	0
Palaemonetes	8 ± 8	0	0	20 ± 20	0	20 ± 20	0	0
other	0	0	0	0	0	0	0	0
Total Animals	12 ± 10	4403 ± 851	2181 ± 305	9898 ± 5477	6120 ± 368	13171 ± 1849	16786 ± 2024	19573 ± 1458

TABLE 24. Station means and standard errors for macroscopically identifiable animals in September 1973 short survey of benthic organisms. Units are numbers per square meter.

TAXON	DC-0	SNC 3-1	NOC 5-1	DC-2	DC-3	DC-4	DC-5	DC-6
Penaezoidea	0	49 ± 12	4 ± 4	222 ± 88	3515 ± 126	6444 ± 1270	13675 ± 6115	10506 ± 690
Caprellidae	0	45 ± 23	69 ± 19	2404 ± 1413	828 ± 556	3878 ± 1478	1757 ± 862	4404 ± 780
Malacostraca	0	110 ± 25	55 ± 17	246 ± 93	6 ± 35	222 ± 101	365 ± 1217	323 ± 455
Stomatopoda	0	4 ± 4	0	0	0	0	61 ± 61	20 ± 20
Sph. nitidum	0	0	0	165 ± 88	20 ± 20	121 ± 93	0	0
Sph. atriatum	0	0	0	40 ± 40	0	0	0	0
Crustacea spp.	0	37 ± 16	12 ± 8	444 ± 88	444 ± 141	1131 ± 526	3596 ± 1814	4828 ± 40
Hydroids	50 ± 35	1248 ± 86	1473 ± 189	946 ± 345	606 ± 485	81 ± 40	81 ± 81	101 ± 73
Hirudinea	0	146 ± 50	0	0	0	182 ± 126	120 ± 93	0
Operculata	0	4 ± 4	8 ± 5	121 ± 61	0	0	0	0
Pulmonata	0	0	0	0	20 ± 20	20 ± 20	0	20 ± 20
other	0	0	0	0	40 ± 40	20 ± 20	0	40 ± 40
Total Animals	57 ± 35	1917 ± 245	1620 ± 147	4322 ± 1305	5534 ± 1157	12119 ± 818	24744 ± 10145	23150 ± 1925

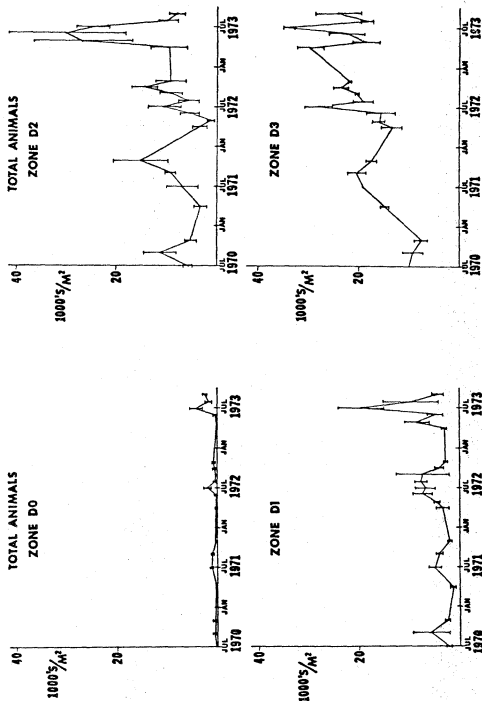


FIGURE 22. Means and standard errors (brackets) by benthic depth zone for total animals at all stations falling within the D (Cook Plant) region over all surveys from July 1970 through September 1973.

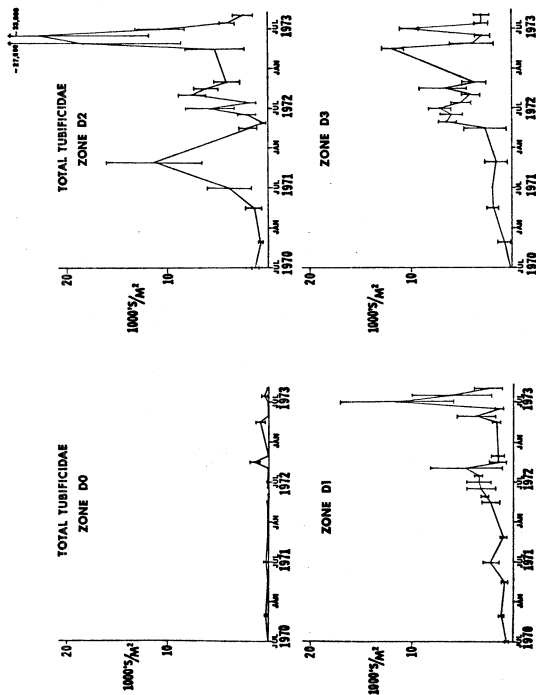


FIGURE 23. Means and standard errors (brackets) by benthic depth zone for Tubificidae at all stations falling within the D (Cook Plant) region over all surveys from July 1970 through September 1973.

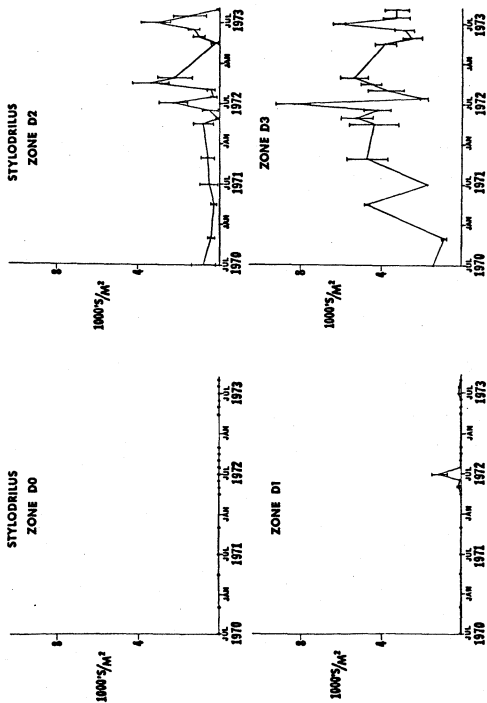


FIGURE 24. Means and standard errors (brackets) by benthic depth zone for *Styrodrius heringianus* at all stations falling within the D (Cook Plant) region over all surveys from July 1970 through September 1973.

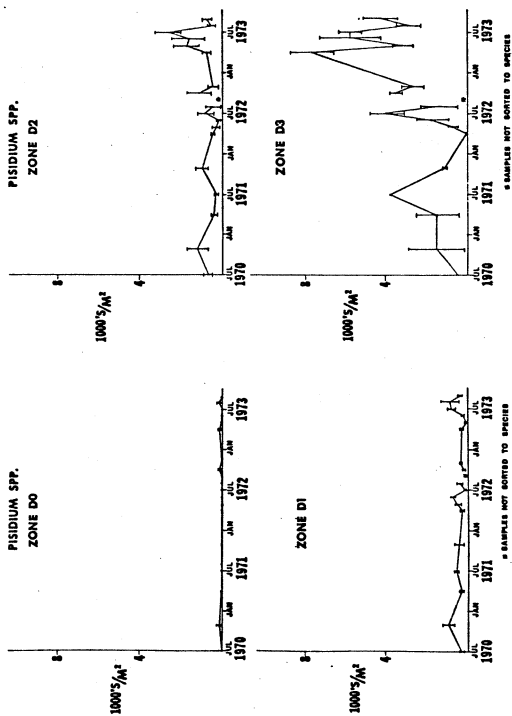


FIGURE 25. Means and standard errors (brackets) by benthic depth zone for *Pisidium* spp. at all stations falling within the D (Cook Plant) region over all surveys from July 1970 through September 1973. *Pisidium* were not separated from *Sphaerium* in a few samples in August 1972.

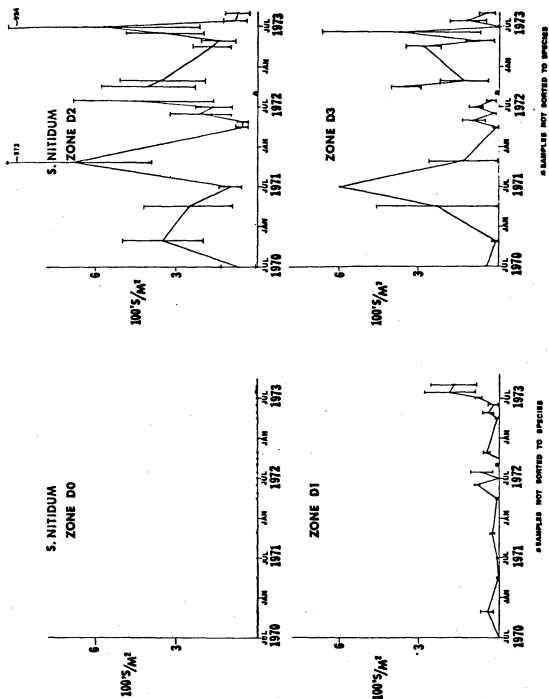


FIGURE 26. Means and standard errors (brackets) by benthic depth zone for *Sphaerium nitidum* at all stations falling within the D (Cook Plant) region over all surveys from July 1970 through September 1973. *Sphaerium nitidum* were not separated from other Sphaeriidae in a few samples in August 1972.

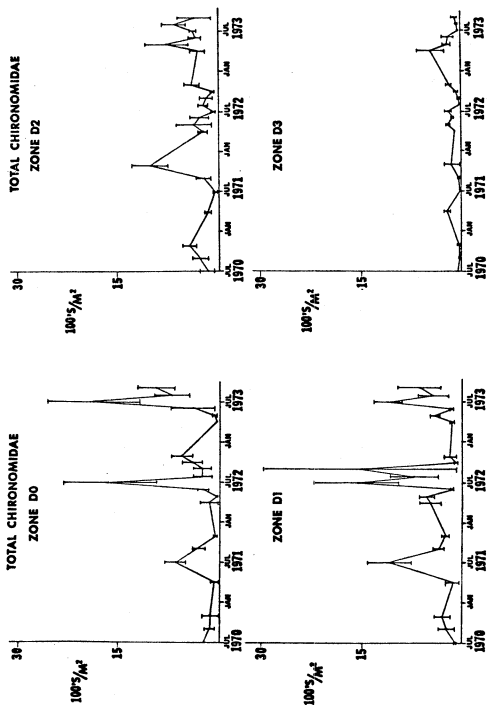


FIGURE 27. Means and standard errors (brackets) by benthic depth zone for Chironomidae at all stations falling within the D (Cook Plant) region over all surveys from July 1970 through September 1973.

1972 when zone 1 had more than zone 2.

The yearly maximum numbers appeared to get larger in successive years, especially from 1972 to 1973. Three of the zones also showed numerical increases in 1972 over 1970 and 1971, but zone 2 did not. The apparent increasing trend may have resulted partly from changes in methodology over this period, however. Addition of short surveys to the sampling program in 1972 increased the likelihood of detecting maxima of short duration which could have occurred in 1970 and 1971. As shown in the "Results" section above, the triplex ponar grab may have collected more animals per unit area than the standard ponar. Its use in the major surveys of July and October 1972 and all subsequent surveys corresponded to higher estimates of total animals, especially in zones 2 and 3. Another change in the sampling program, *i.e.*, randomization of station locations for major surveys beginning in July 1972 may have contributed to apparent increases also. This effect is confounded with the use of the triplex ponar, however, and would be expected to vary from survey to survey as the locations of randomized stations change, so that it is difficult to test for it in the data. The greatest increase among the separate taxa was exhibited by Total Tubificidae, while *Pentoporeia* and Total Chironomidae increased very little.

Total Tubificidae (Fig. 23) played a major role in the fluctuations of total animals, particularly in zones 1 and 2. In those zones, tubificid worms often contributed more than 50% of total animals, and the survey to survey variations of Tubificidae and total animals had nearly identical patterns. Total Tubificidae were relatively less important in zone 3, but variations in numbers of tubificids still had marked effects on means for total animals, especially in 1972 and 1973. The standard errors of Tubificidae means within zones were much larger than for total animals, and much greater in proportion

to the means in 1972 and 1973 than 1970 and 1971 and in zones 0-2 than in zone 3. This was largely due to the fact that means for short surveys were based on fewer observations than those for major surveys, and major survey data in 1972-73 were collected with the smaller grab size. For instance, zone 1 was represented on short surveys by only three observations at a single station (DC-2), and by three (mean) triplex chamber observations from three different stations on systematic-random surveys, but by four to seven full-sized ponar observations from as many stations on major grid surveys in 1970-1972. Replication conducted in the grab comparison survey showed that Tubificidae was one of the most variable taxa in numbers per grab. There was no consistent seasonal pattern in numbers of Tubificidae, but April means were usually lower than many monthly means later in each year.

Stylodrilus heringianus (Fig. 24) was one of the most abundant individual species in the survey area, particularly in zones 2 and 3. Its relative importance, however, diminished over the years as total animals and Tubificidae increased. Its maximum numbers in 1972 and 1973 were greater than in 1970 and 1971 in zone 2, but there was little year to year difference in zone 3. In both 1972 and 1973 there were population increases from April to July, followed by sharp declines between July and August surveys in both zones 2 and 3. In 1972 a second increase was observed during the fall; 1973 surveys from that period have not yet been sorted. Corroborating data, such as abundance of cocoons or population size or maturity frequencies, have not been collected for *Stylodrilus*.

Pisidium spp. (Fig. 25) as a group contributed only slightly less than *Stylodrilus* to the number of total animals. Like *Stylodrilus*, *Pisidium* was most abundant in zone 3. These smaller fingernail clams did not increase noticeably in survey estimates until 1973, and contributed insignificantly to

zone 1 increases in that year. There was no consistent seasonal pattern in survey data for numbers of *Pisidium* collected up to August 1973.

Other taxa contributed only very small proportions of total animals. *Sphaerium nitidum* (Fig. 26) was extremely variable within zones, but was nearly always rare at depths shallower than 16 m. The broad standard errors for monthly means preclude any statements about seasonality of population size. There do not appear to have been any year-to-year increases in this species. Chironomidae (Fig. 27) were highly seasonal in numbers in zones 0 and 1, with July maximums in every year but 1970. There appeared to be no tendency toward year-to-year increases in numbers in any zone. In zones 2 and 3, Chironomidae were less seasonal and had lower maximum numbers. As reported in earlier surveys (Mozley 1974), the species composition of Chironomidae changes markedly from spring into summer and again from summer to late fall.

Pontoporeia affinis (Fig. 28) contributed somewhat to the trend of increasing total animals in zone 1, but less so in zone 2 and not at all in zone 3, although it was the most abundant single species in the survey area. The increases from 1971 to 1972 and 1973 in zone 1 were attributable to greater reproductive success or reduced mortality in the smaller size classes. The slightly larger populations of young could have been related to their early release in 1973.

Seasonality of Pontoporeia size distribution

This is the most abundant single species in the survey as a whole, and has pronounced month-to-month changes in population size and age distribution in the shallower zones. These changes provide some information about the growth rate and the timing of reproduction, and can be compared from year to year to determine how often the population reproduces. Finally, size-distribution data can show whether increases in the numbers per m² were the result

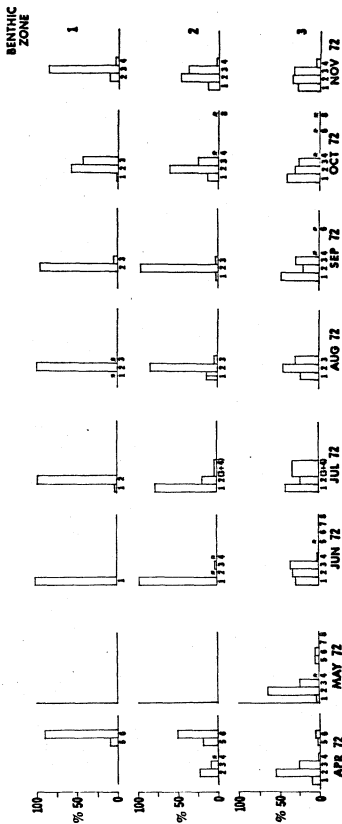


FIGURE 29. Size and sex class proportions for *Pontoporeia affinis* populations in benthic depth zones 1, 2 and 3 for surveys between April 1972 and September 1973. Empty coordinates indicate lack of sufficient specimens. * means <2% but >0. Classes: 1-<3mm, 2-3 to 4.9mm, 3-5 to 7mm immature, 4->7mm immature, 5-gravid females, 6-spent females, 7-mature males of *filicornis*-type, 8-mature males of *breuticornis*-type.

**BENTHIC
ZONE**

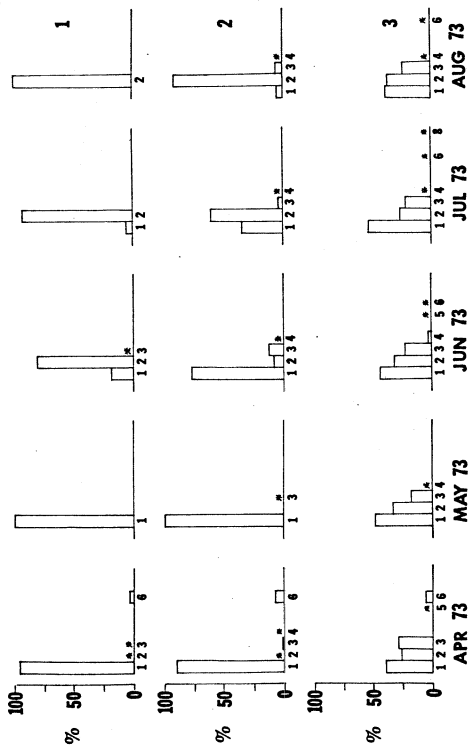


FIGURE 29 continued.

of recruitment of young by reproduction, or of older specimens by migrations.

The general pattern of reproduction was outlined in Part XIII (Mozley 1973a) and repeated in Part XX (Mozley 1974). There were too few *P. affinis* present in zone 0 to analyze for size composition. In zone 1, a few *Pontoporeia* were present in major surveys of 1970 and 1971, but in 1972 there were many more, and a June-September period of large numbers was contrasted with lower numbers per m² in earlier and later months each year (Fig. 28). In 1973, April values were higher than in previous years, but still small in comparison to May-July data. August numbers were lower again, and September 1973 samples showed a further decrease. The size data (Fig. 29) show that springtime increases were due to reproduction, for spent and gravid females in April were replaced by the smallest size class in later months. Unlike this month in previous years, April 1973 saw a predominance of the newly emerged young, and a few spent females. In 1973 the major annual recruitment appears to have occurred at least one and possibly two months earlier than in previous years. Despite the early release of young, however, the 1973 population size (length) distribution was practically identical to 1972 size distribution by August. At depths of 8-16 m, *P. affinis* appears to have a one year life cycle.

As far as present data extend, it appears that a sharp late summer or late autumn decline in *P. affinis* populations occurred in benthic zone 1 and possibly zones 2 and 3 as well. This decline did not occur in the same month from year to year. In 1970 and 1971 it appeared to happen between September and November, between August and September in 1972, and in 1973 there was a sharp drop in zone 1 between July and August. Data from fish larvae tows in 1973 indicate that *Pontoporeia* occurred in the water column in August but not in earlier months. This could be interpreted as a late-summer/autumn pattern

of seasonal mortality and offshore migration. Fish stomach contents analysis for 1973 is underway, but summer-autumn stomachs have not been analyzed yet. They would support the hypothesis of seasonal mortality if they indicated a major increase in predation on *Pontoporeia* in August.

As has been pointed out (Mozley 1974), the spent females, i.e. those which have released their young and are dying, were in evidence a month earlier than the young they must have released. The most likely explanation for the absence of young in these samples is that they are small enough to escape through our screens. Still, it is surprising that none at all were caught when other minute animals such as harpacticoid copepods and nematodes were frequently retained in the collections.

In benthic zone 2 there was usually a wider spread of size groups present in any given month. The once-yearly reproductive cycle appeared to be true of this depth interval just as for zone 1, except that spring release of young was somewhat later (a few weeks?) than in zone 1. This difference was maintained through 1972 as a slight lag in growth in zone 2, so that in November 1972 zone 1 *Pontoporeia* were almost all longer than 5 mm while those in zone 2 were mostly shorter. A small percentage of individuals in zone 2 did not mature in a single year. The very successful reproduction in 1972 and 1973 obscured these few slower individuals in the percentage data but they were more in evidence in 1970 and 1971 (Mozley 1974).

In benthic zone 3 there were at least two year classes present in every month. Some reproduction occurred in spring and early summer each year, but growth beyond a length of 3 mm was relatively slow. The influx of young appeared to begin as early as May and continue through the summer. As in shallower zones, spent females were the most common mature individuals. Even so, they were never a major proportion of the population between May and

November. Clearly, most of the maturation, mating and brooding of *Pontoporeia* to depths of at least 40 m (outer limit of the survey) occurred in the months between November and April, and population maximums occurred in summer and autumn when the young were released from the brood chamber. The seasonal fluctuations in population size were much greater proportionally in the shallower zones.

All of the pronounced increases from one survey to the next in number of *Pontoporeia* per m^2 were accompanied by appearance of a large percentage of the population in the smallest size classes. If interzonal migration of older individuals was taking place, it was numerically unimportant to the populations. Migration from the shallower to the deeper depth intervals would be very difficult to detect, however. The number of *P. affinis* per m^2 in shallower zones was smaller than in deeper zones, and the surface area of lake bottom within zone 1 was considerably less than that within zone 2 (e.g., Fig. 47 on p. 220 in Mozley 1973a). Even if a substantial proportion of the amphipods from zone 1 were migrating from zone 1 to zone 2, the change in abundance and age distribution of zone 2 populations would be negligible in comparison to the variation among replicates within that zone.

MACROINVERTEBRATES IN FISH LARVAE TOWS

As a result of the discovery of benthic animals in intake water during pump trials in winter 1973 (Mozley 1973a), we decided to attempt an estimate of the amount of macroinvertebrates suspended in the water column as a part of the monthly surveys. The design for collections of fish larvae was ideally suited to this purpose so those samples were used for estimates of macroinvertebrates as well. Full description of the methodology of fish larvae collections is contained in the section on fish in this special report.

The differences in species of macroinvertebrates found in grab samples

and in fish larvae tows (Table 2) were considerable. A total of 28 species, 21 of which are mites or insects in several orders, have been identified so far only in fish larvae collections, while 47 species have been found only in grab samples (mainly Mollusca and Tubificidae); 31 occurred in both (mainly Chironomidae, Naididae and Crustacea). Several of the Chironomidae which were found only in fish larvae tows are more typical of habitats such as algal growths on pilings and rocks or aquatic macrophytes (e.g., *Cricotopus* cfr. *syvestris*, *Tanytarsus*, *Rheotanytarsus*). A few forms in fish larvae tows would be expected to be only accidental inhabitants of Lake Michigan, such as the dipterans *Simulium* and *Tipula*. Evidently, the influx of animals from other bodies of water at the edge of the lake (e.g., Grand Marais Lakes) and the importance of rocky substrata are greater than would be expected in this part of the lake. The water mites are probably planktonic most of the time. Fish larvae tows sampled much larger amounts of habitat than grab casts.

Macroinvertebrates in fish larvae tows were taxonomically diverse, but relatively sparse in most collections. Total numbers per m^3 are plotted against month of collection at night and in the day in fish larvae tows in Figs. 30 through 36. There were never more than $2/m^3$ in the water column in the daytime (mean of 2-4 fish larvae tows). March tows in the surf (stations A, B and F) caught very few macroinvertebrates, but many times more appeared in May. Small and large-scale spatial variability in the size of the concentrations and in the ratio of day to night abundance was sometimes large. This indicates that local and transitory action of wind, waves and current on the bottom may readily overshadow a typical nocturnal migration behavior. Moreover, the time of day or night when the fish larvae tows were made varied from station to station and month to month. As a rule, however, nocturnal densities of swimming macroinvertebrates were much greater than in

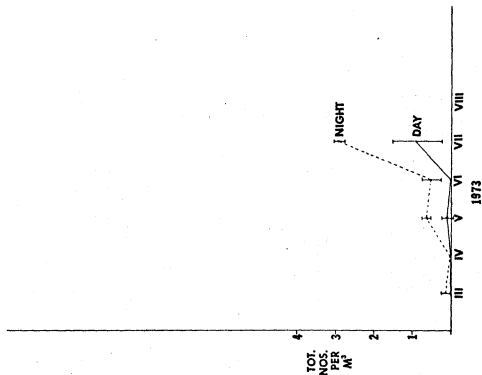


FIGURE 30. Total numbers of benthic macroinvertebrates and water mites per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station A.

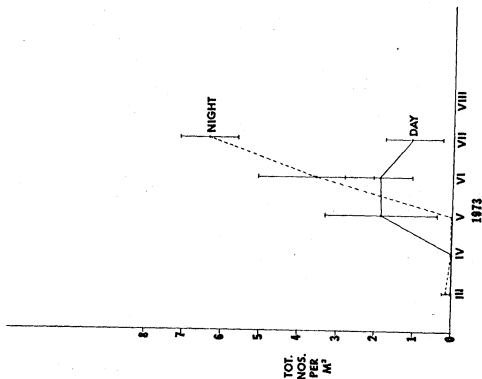


FIGURE 31. Total numbers of benthic macroinvertebrates and water mites per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station B.

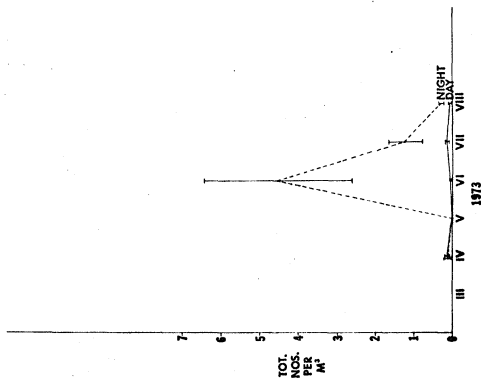


FIGURE 32. Total numbers of benthic macroinvertebrates and water mites per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station C.

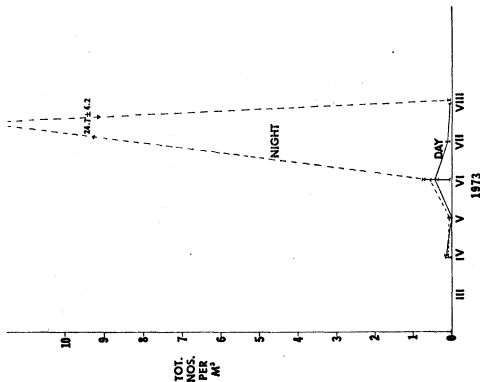


FIGURE 33. Total numbers of benthic macroinvertebrates and water mites per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station D.

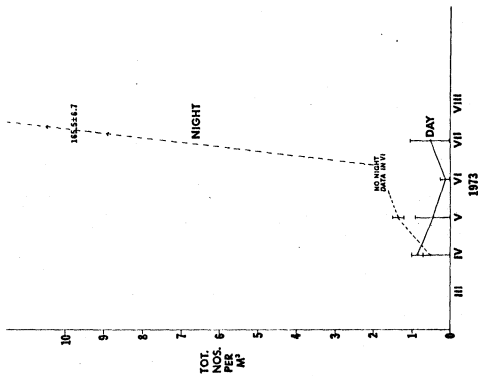


FIGURE 34. Total numbers of benthic macroinvertebrates and water mites per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station P.

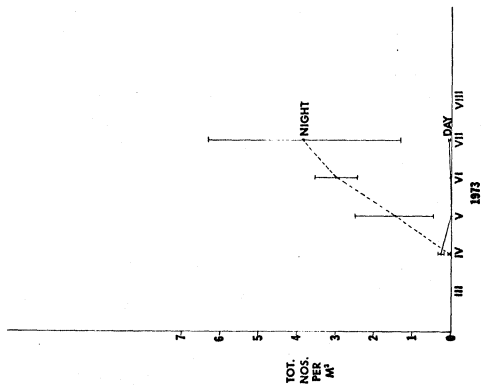


FIGURE 35. Total numbers of benthic macroinvertebrates and water mites per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station G.

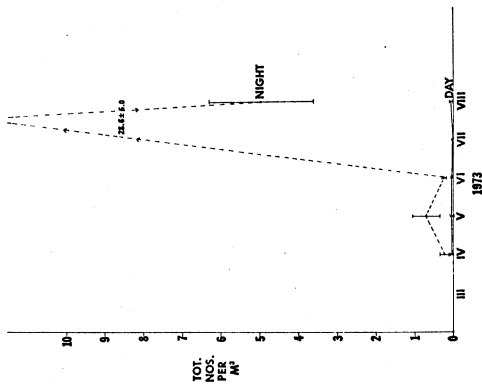


FIGURE 36. Total numbers of benthic macroinvertebrates and water mice per cubic meter in #2 plankton net collections expressed as means and standard errors (brackets) of all tows for each 1973 monthly survey at fishing station H.

the daytime, and 1973 densities, at least, were maximal in July.

Four taxa made up most of the macroinvertebrates (Figs. 37-40). *Pontoporeia* was rare except in August, even though it was present in grab collections from zone 0 from April through July. The other three taxa were present in almost every nocturnal tow. Hydracarina showed some tendency to avoid the shallowest sampling stations, surf locations A, B and F (approximately 1 m deep). Naididae and Chironomidae densities corresponded to the pattern of benthic abundances for each, i.e., there was a large maximum for both in July 1973. Data from daytime collections and months before May were not illustrated due to the lack of sufficient numbers of specimens.

The densities of the more abundant and frequently-occurring species in night tows in July 1973 are shown by station in Figs. 41, 42 and 43. The larval instars of *Chironomus* are shown separately within each histogram column to point out the predominance of the smaller, early instars among larvae above the bottom. The first two instars are small enough to escape through the benthos screen, so that their benthic abundances were greatly underestimated in the grab casts. When densities of swimming larvae in the later instars (0.5 to $1.0/\text{m}^3$) were compared with grab data, it was found that very small percentages of chironomid populations were above bottom, even at night in July. The grab collections from zone S0 in that month yielded an estimated mean of about $2900 \text{ Chironomidae}/\text{m}^2$. Assuming a density of $1/\text{m}^3$ over that zone at night for larger larvae and a mean depth of 4 m, approximately 0.14% of the larger benthic larvae became planktonic at night. The proportion of smaller, early instar larvae which move into the water column at night may be larger than this.

The species composition of Chironomidae larvae was very different in fish larvae tows in the surf (stations A, B and F) from that of zone 0 benthic

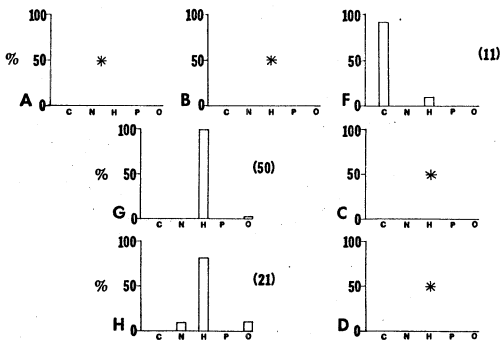


FIGURE 37. Percentages due to the more abundant taxa of macroinvertebrates at each fishing station (large letters) in May 1973, #2 plankton net. Numbers in parentheses are totals caught at each station. C = Chironomidae, N = Naididae, H = Hydracarina, P = *Pontoporeia*, O = other taxa, * = insufficient specimens.

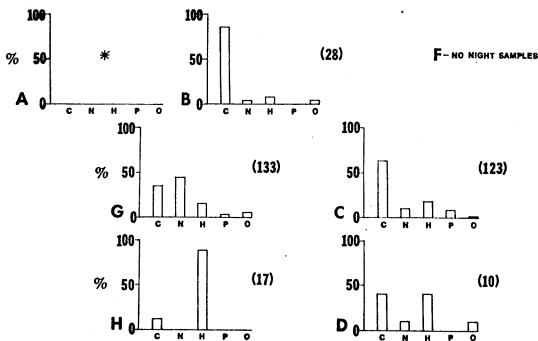


FIGURE 38. Percentages due to the more abundant taxa of macroinvertebrates at each fishing station (large letters) in June 1973, #2 plankton net. Numbers in parentheses are totals caught at each station. C = Chironomidae, N = Naididae, H = Hydracarina, P = *Pontoporeia*, O = other taxa, * = insufficient specimens.

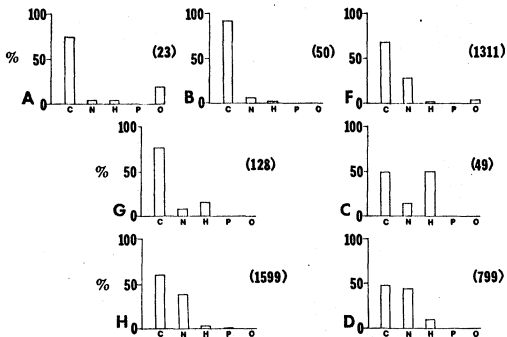


FIGURE 39. Percentages due to the more abundant taxa of macroinvertebrates at each fishing station (large letters) in July 1973, #2 plankton net. Numbers in parentheses are totals caught at each station. C = Chironomidae, N = Naididae, H = Hydracarina, P = Pontoporeia, O = other taxa, * = insufficient specimens.

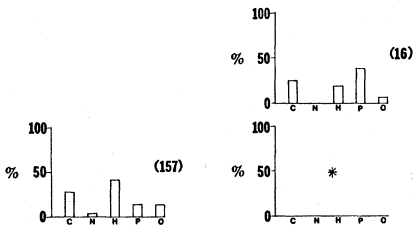
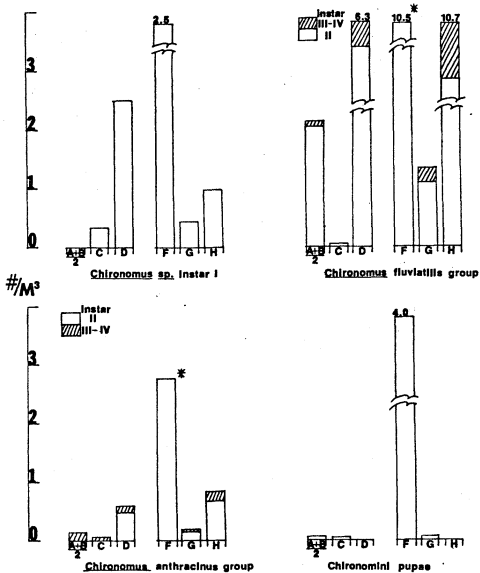


FIGURE 40. Percentages due to the more abundant taxa of macroinvertebrates at each fishing station (large letters) in August 1973, #2 plankton net. Numbers in parentheses are totals caught at each station. C = Chironomidae, N = Naididae, H = Hydracarina, P = Pontoporeia, O = other taxa, * = insufficient specimens.



*NOTE: NO DISTINCTION BETWEEN INSTARS WAS MADE.

FIGURE 41. Numbers per cubic meter of the two types of *Chironomus* larvae, first instars of both (combined) and total Chironomini pupae in nocturnal tows of the #2 plankton net at fishing stations (letters along abscissas) in July 1973.

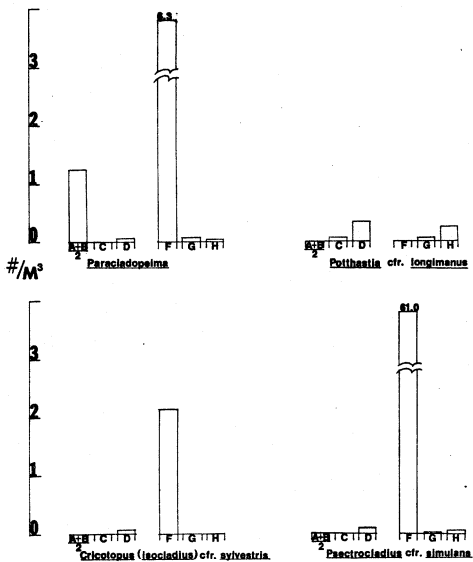


FIGURE 42. Numbers per cubic meter of four smaller Chironomidae larvae in nocturnal tows of the #2 plankton net at fishing stations (letters along abscissas) in July 1973. The *Paracladopelma* species is *P. tylus*, earlier misidentified as *P. nereis*.

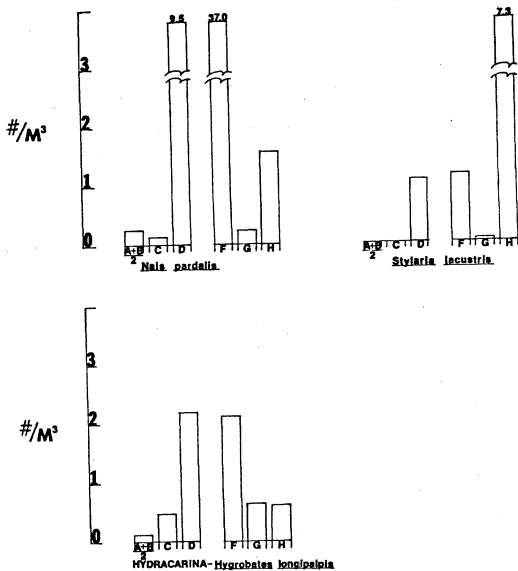


FIGURE 43. Numbers per cubic meter of the two more abundant Naididae species and the predominant water mite species in nocturnal tows of the #2 plankton net at fishing stations (letters along abscissas) in July 1973.

samples. Selected grab casts were sorted to species for preliminary comparisons. The most abundant larval types were *Cladotanytarsus* sp. 2 and *Chironomus fluviatilis*-group, with former about 3 to 4 times as numerous as the latter. *Paracladopelma tylus*, *P. cfr. obscura* and several other species contributed the remaining 5-15%. In fish larvae tows in the surf, however, *Psectrocladius* cfr. *simulans* larvae (and *Conchapelopia* sp. at F) were very numerous, with lesser contributions from *Chironomus fluviatilis*-group and *Paracladopelma nereis* (Figs. 41 and 42). Farther from the beach (stations C, D, G and H) the only abundant chironomid in fish larvae tows was *C. fluviatilis*-group. *Conchapelopia* sp. was not plotted in the figures because it was absent from the other fish larvae sampling stations. Similarly, *Cricotopus* cfr. *sylvestris* was numerous only at night at station F, but occurred occasionally at stations C (daytime) and D.

The species which accounted for almost all Hydracarina was *Hygrobates longipalpis*, a predator on the pupae and adults of Chironomidae. This species was relatively abundant ($>2/m^3$) in the surf tows only in July night collections at station F (Fig. 43), which was also the time and place of largest densities of Chironomidae pupae.

Potthastia cfr. *longimanus* has been very rare in earlier summer benthic surveys, so its frequent presence in July fish larvae tows was somewhat surprising. All individuals in fish larvae collections were in the small, early instars, and probably escaped through the screens in which grab collections were washed.

The Naididae in fish larvae tows were also very small, and composed of only a part of the species common in zone 0 grab samples. Most were in the species *Nais pardalis* and *Stylaria lacustris* (Fig. 43), while *Chaetogaster*, *Uncinaxis uncinata*, *Piguetella michiganensis* and *Ophidonais serpentina* were often more abundant than these in grab samples.

Occurrence of Mysis relicta

Mysis occurred occasionally in all types of samples of macroinvertebrates. In preliminary daytime collections from the Cook Plant's intake forebay in February 1973, *Mysis* density was 0.14 individual per m^3 . In tows of the #2 net at fishing stations in the lake, *Mysis* was less common. In the months of March, June and July 1973, none were collected at all. In April and May 1973, *Mysis* was collected at night at two stations in each month, but its density (0.015 to 0.02 per m^3) at those stations was little more than one-tenth that in February intake forebay collections. At other stations and in the daytime, none were collected. In August 1973, *Mysis* was slightly more common, occurring at three stations at densities from 0.017 to 0.091 per m^3 . Again, none were collected in the daytime.

Mysis occurred in grab-samples from benthic zone 3 consistently, except for the July 1972 survey. Abundance estimates in this zone ranged otherwise from 10 to 150 per m^2 (average over all ponar casts from this zone in each survey), with the largest concentrations occurring in July and August 1973. *Mysis* was present in zone 2 on only four of the fourteen 1972-73 surveys which have been sorted so far. In those four surveys, abundance estimates were between 2 and 32 per m^2 . Collections in zones 0 and 1 included *Mysis* only in July 1973, at mean abundances of 1 and 4 per m^2 , respectively. Trawl collections occasionally included *Mysis*, but no records of numbers or frequency have been made.

Mysis tended to be most numerous in zone 3 (grab data) in 1972 and 1973 in the month of August, but in 1972, October was the month with second-greatest abundance. At this point, our collections are inadequate to determine whether seasonal regularities exist in *Mysis* population sizes from year to year. It is clear that *Mysis* is generally rare or absent in the shallower zones near shore, at least from April to November.

DISCUSSION

DETECTION OF CHANGES

The capability to detect future changes is one of the most important issues in preoperational environmental surveys. Many judgments of change in Great Lakes benthos have been primarily qualitative and based on information from relatively few years or seasons. The fact that these judgments have been accepted shows that such subjective approaches will continue to receive attention. However, it will also be necessary to estimate the probabilities of making errors in these judgments.

The sizes of changes in numbers of total animals per unit area which will be statistically detectable in comparison to preoperational means have been calculated to be about $4000/\text{m}^2$ in benthic zone 0 and $21,000/\text{m}^2$ in benthic zones 1-3 (Figs. 9 and 10). In zone 0, this represents about 160-450% increases in monthly means (compare Tables 12 through 15), while in zones 1-3 it represents 60 to 650% increases (or decreases), largely depending on the zone. Deeper zones usually require lower percentage increases in the means to exceed the least detectable true difference because the present means are high (and their relative variability is less). The Limnetics, Inc. preliminary study of zoobenthic numerical variability at depths of less than 7.4 m (R. Sayrs and J. Zar, personal communication*) indicated that differences greater than $1400/\text{m}^2$ (about 2-3 times the overall mean in that area) would be detectable statistically at the .05 significance level and the .99 power level. No other zoobenthos study to our knowledge has attempted this

*Dr. Zar and Mr. Sayrs adapted this approach to zoobenthos data independently, and suggested the use of within-cell sums of squares as a basis for the calculation. Dr. Johnston of our group originally suggested the formula for δ to me and advised me in setting up the calculations.

sort of estimate of survey sensitivity.

A few researchers have considered the relationship of number of replicate observations to precision of estimates. Dugdale (1955) determined the precision of numerical estimates of *Chironomus* larvae in Lake Mendota as a function of number of grab casts, and found that 10 to 25 casts would be necessary to obtain a standard-error-to-mean ratio of 0.1 consistently. This was more casts than the available time and support would allow if he were to complete the primary objectives of his study of secondary production, so he was forced to accept poorer precision levels (0.5 - 0.85) derived from a maximum possible sample of 5 replicates per station. Beak Consultants, Inc. (1972) reported a test of the effect of reducing the number of observations per station from 6 to 3 at several stations on the mean and variance of total animals and of a species diversity index. Their approach was to calculate F-ratios and "t"-tests for differences between the variance and mean of a random subsample of 3 of the 6, and the same parameters for all six observations. Since the data compared were not independent, the tests were invalid.

Other attempts to determine the necessary number of replicates have not been subject to error probability statements. Brinkhurst (1967) compared the percentage composition of Tubificidae species in 4 grab casts with that from 60 casts at the same station, and finding no major differences, concluded that 4 casts adequately represented Tubificidae composition at any station. Longhurst (1959, and reprinted in Ford and Hazen 1972) proposed and illustrated a method for sequential comparisons which counseled the investigator to take only enough replicates to detect the presence of those species contributing important fractions of the total numbers. When new species recruited in two or three successive grabs made up less than about 5% of the total to that

point, replication was halted. Elliott (1971) outlined a method for determining the number of replicates necessary to achieve a given standard-error-to-mean ratio, and suggested that a ratio of 0.2 was practicable and appropriate. Many investigators have had misgivings about the capability of their data to support conclusions statistically, and have responded simply by avoiding interpretation of differences unless they exceed a factor of 10 (e.g., Johnson and Matheson 1968).

In the comparison of number of replicate observations with least detectable true difference (δ), it was found that even very large numbers of replicates did not permit detection of changes on the order of 50% increases or decreases in the mean. Thus a practical limit is set to the sensitivity of any survey by natural spatial variability of the zoobenthic distributions, i.e., the occurrence of occasional, very dense patches of animals. The advantage of taking additional replicates on a single survey becomes proportionally very small between 5 and 10 replicates per zone, and this is due more to other coefficients in the formula for δ than to the natural population variability. Both the rate of change of the t-values and of the standard error per unit change in number of observations (or degrees of freedom) decreases with increasing n. The 15 replicates per zone in benthic depth zone 0 regions were not excessive however, for the means for total animals were lower and the relative variations were greater than in deeper zones. Also, this zone will be the most directly exposed to discharge effects. Relatively little additional laboratory time is required to sort more casts from this zone, because numbers per cast are low. The 9 replicates per zone farther from shore constituted a practicable and efficient sampling effort when set against the small advantage which would be obtained by further sampling.

Because transformation of the data offered the advantage of permitting

statistical detection of extinction of the animals from a zone, its use will be continued in further analysis. It would appear that extinction is a more serious form of environmental change than increases in total animals, particularly since there is some indication that a few taxa have been increasing from year to year in the lake before plant operation.

The question of our capacity to detect shifts in species composition of zoobenthos has not been confronted statistically as yet. One approach would be to apply the procedure for least detectable true difference to individual taxa which were judged to be important in ecological interactions within the lake. Since estimates of numbers of *Pontoporeia* and total Chironomidae were more precise than for total numbers, the values for δ would be smaller relative to the means, but changes in *Pisidium*, *Sphaerium* or total Tubificidae would have to be much larger to be statistically significant. Another approach would be to apply techniques such as coefficient of community (Johnson and Brinkhurst 1971) or discriminant analysis (Green 1974) to the species composition data. These techniques are not subject to error-probability statements, however. This has not been done with our data yet, but the year-to-year increases in importance of Naididae in benthic zones 0 and 1 indicate that these measures too, may have considerable preoperational variability in nearshore Lake Michigan.

The illustrations of the effects of increasing the number of replicates on percentage species composition at the two ponar comparison stations (Figs. 7 and 8) are analogous to Longhurst's (1959) approach. Although only a few replicates were needed to show the presence of common taxa (except for *Paracladopelma* cfr. *rolli* at SDC-.5-1), between 8 and 10 were collected before the rank order was the same as for all 30 casts combined. If the freakish patch of *Pisidium* were omitted from the data at DC-4, the final

rank order would have been different (*Pontoporeia* dominating) and would have been reached after fewer replicates. Longhurst's finding that 4 or 5 replicate casts were sufficient to detect the presence of the more numerous species at a marine station was more or less true at the two ponar comparison stations here. However, no generalizations can be drawn because so few stations have been extensively sampled.

SPECIES COMPOSITION AND BENTHIC ZONATION

The species composition of zoobenthos at the Cook Plant in April 1972 did not reveal any pronounced changes from earlier surveys when regular seasonal differences were taken into account. The largest onshore-offshore differences occurred at a depth of about 8 m. Shallower than this, *Chironomus fluviatilis*-group, immature Tubificidae and *Cryptochironomus* sp. 2 were the most numerous taxa. The summer species of *Paracladopelma* and *Parachironomus* (Mozley and Garcia 1972; Mozley 1974) were rare or absent. Beyond the 8 m depth contour, numbers and kinds of zoobenthos increased rapidly. Between the 8 and 24 m contours (benthic depth zones 1 and 2) total animals varied widely from station to station. Deeper than 24 m, most stations had populations over 10,000 per m². This pattern has been explained previously (Mozley and Garcia 1972) as the result of factors controlling sedimentation. Where wave action and nearshore currents keep the sand bottom in almost continual motion, few benthic animals can find suitable food and shelter. As fine sedimentation increases with distance from shore (see also Seibel 1974), animals which ingest or filter fine particles for food find much better living conditions. In the transitional zones between the surf and the zone-3 muds, the irregularity of sediment grain sizes and accumulation rates probably has a large effect on numbers of benthic animals. It should be remembered, however, that

visible sediment differences at the ponar comparison stations were not helpful in explaining faunal patchiness. Other causes of patchiness could result from the relatively low mobility of the viviparous Sphaeriidae and the Oligochaeta. Oligochaeta should tend to reproduce more frequently and successfully where food is abundant, and they are not known to have any dispersal mechanisms other than by crawling or accidental transport in lumps of substrate (Tubificidae and Lumbriculidae). Brinkhurst, Chua and Kaushik (1972) found that Tubificidae species can interact symbiotically to improve growth rates and feeding efficiencies, and implied that some species may seek one another out and live preferentially in clumps. More mobile taxa such as *Pontoporeia* and Chironomidae (Mundie 1959) should be and usually are (Tables 5 and 6) more randomly dispersed.

A few species appear to be distributed discontinuously with increasing depth, especially *Sphaerium nitidum* and *Stylodrilus heringianus*. Their higher abundances were at similar stations. Lakeward from the beach, high numbers began rather abruptly around a depth of 20 m (Table 11). This corresponded approximately with a break in the percentage silt in the sediments analyzed by Seibel (1974). It is also near or just below the lower extent of the usual summer thermocline (exclusive of seiching). Only three species appear to be restricted mainly to depths over 24 m, *Heterotrissocoelatus* cfr. *subpilosus*, *Limnodrilus udekemianus* and *Mysis relicta*. The last almost certainly occurs nearer shore (Reynolds and DeGraeve 1972) but is rare and can probably avoid daytime grab-samples easily near the well-lit, shallower bottoms.

The most abundant single species in the survey area, as in Lake Michigan, as a whole, was *Pontoporeia affinis*. Tubificidae as a group were often more abundant in the central and southern regions, however. The tendency toward

more Oligochaeta, proportionally and in numbers per m², in the southern part of Lake Michigan was first noted by Cook and Powers (1964) and Powers and Robertson (1965), and later by the U. S. Department of the Interior (1968) and Mozley and Alley (1973). All authors took this as an indication of pollution or enrichment of the southern region, at least in comparison to central regions of Lake Michigan. The apparent increases in Tubificidae over the years of the Cook survey suggest that the Oligochaeta are still increasing, and may even be doing so at an accelerated rate in the last few years. Improvements in technique may be responsible for some of the apparent increases, however.

Although Cook and Powers (1964) suggested that materials introduced into Lake Michigan by the St. Joseph River were a primary cause of increased Oligochaeta, present data indicate that the southern region of the survey area is more enriched than the northern region, which is much closer (only a few km SW) to the river mouth. Mozley and Alley (1973) showed that dense patches of worms and higher numbers of worms overall were most often found at depths less than 40 m. We proposed that materials added by rivers were redistributed and deposited irregularly over large regions of the nearshore zone. This could mean that there might be no obvious relationship of numbers of zoobenthos to point sources of enrichment along the shoreline.

The species composition of Tubificidae also indicates some effects of eutrophication in the survey area when compared with the criteria of Brinkhurst (1969). The most numerous species were *Limnodrilus hoffmeisteri* and *Potamotheix moldaviensis* in April 1972, but *Tubifex tubifex*, *Limnodrilus cervix*, *L. clapparedianus* and *Peloscoides freyi* were common in summer and autumn surveys (Mozley 1973 and 1973b). This assemblage occurs near the "eutrophic"- "mesotrophic" boundary in the Brinkhurst system of benthic

enrichment levels. Unusually dense patches of *Oligochaeta* are often composed mainly of *L. hoffmeisteri* and *L. cervix* or *Tubifex tubifex* immatures.

The tendency for Tubificidae to be more abundant toward the south region was mirrored to some extent by a tendency for *Pontoporeia* to be more numerous in the north region. Declining numbers of Amphipoda (= *Pontoporeia*) from Benton Harbor southward were also noted by Powers and Robertson (1965). Reduced numbers of *Pontoporeia* were taken as an indication of pollution by the U. S. Department of the Interior (1968). These and other indicative characteristics of the Cook area zoobenthos show that many "oligotrophic" species are still well established, but the species assemblages have changed and are probably still changing toward those characteristic of polluted near-shore areas of the Great Lakes.

Comparison of species found at the Cook Plant with those recorded from other areas of the lake is difficult, because so few other nearshore surveys have provided full species data. Truchan (1970) found many kinds of Chironomidae near the Campbell (fossil-fuel) Power Plant at Port Sheldon, just south of Holland, Michigan, but the names he used were not directly comparable to those used here. Upon reexamination of his reference slides at the Department of Natural Resources in Lansing¹, they were found to include all the species which were characteristic of zone 0 in the Cook area, but also a few individuals in another genus, *Dicorotendipes*, and other species in familiar genera such as *Parachironomus* cfr. *abortivus*, *P.* cfr. *pectinatellae* and *Polypedilum* cfr. *illinoense*. He found *Hyaella asteca* and a species of Gammaridae, which are either not present or very rare in the Cook area. *Peloscoides freyi* is the only Tubificidae species near the Cook area which is

¹The author thanks Mr. George Jackson for assistance in the reexamination of DNR materials.

rare over most other parts of Lake Michigan (Hiltunen 1967; Howmiller and Beeton 1970). *Sphaerium nitidum* is much more numerous near the Cook Plant than has been reported for any other part of the Great Lakes (Mozley and Garcia 1972). The latter two species are both common in reference areas as well as some distance from shore near the plant, so there is no reason to believe that the entire populations of these organisms will be seriously damaged by plant effects. *Sphaerium striatinum*, which was somewhat more numerous opposite the plant than in the reference areas, is one of the more widespread and common Great Lakes Sphaeriidae (Brinkhurst et al. 1968; Henson and Herrington 1965; Robertson 1967).

The variety of species which occurred in fish larvae tows, and their sheer numbers in July night samples, were at first a bit surprising. The nocturnal, vertical migrations of larger Crustacea have been known for about a decade in the Great Lakes (Beeton 1969; McNaught and Hasler 1966; Marzolf 1965; Wells 1968), but the dominant taxa in fish larvae tows near shore were Chironomidae, water mites and Naididae. Modlin and Gannon (1973) report the occurrence of water mite species in plankton collections, including the one which was most numerous at the Cook Plant, *Hygrobates longipalpis*. The first instar of many Chironomidae is planktonic, apparently as a dispersal mechanism in lakes (Lellak 1968; Oliver 1971). Later instars have also been found above bottom, however, and especially at night. The most detailed report of migrating benthos was presented by Mundie (1959) in Lac la Ronge, Saskatchewan. He found *Mysis relicta*, *Pontoporeia affinis*, *Hyalella azteca*, Ephemeroptera, Ceratopogonidae (Diptera), Chironomidae in at least 3 genera and water mites in surface tows of a 0.75 mm mesh net, and showed that almost all migration occurred at night. His most numerous taxon was a chironomid in the genus *Procladius* (= *Psilotanypus*) which was observed at densities approximating

20 per m³. This was about the same as for total chironomids at the Cook Plant. Our winter collections from the intake forebay with plankton nets included *Procladius* (Mozley 1973a). Pennak (1953) states that Naididae often swim, but there appear to be no reports of such behavior in the Great Lakes.

Although diverse and occasionally abundant in fish larvae tows, zoobenthos above bottom were never more than a small fraction of those in the bottoms below. Although only a small proportion of total Chironomidae were found above bottom at any given time, most larvae are probably planktonic at one or more periods in their development, and especially in the first instar. The conditions of maximum migration appear to be summer nights when Chironomidae are pupating or hatching from the eggs into planktonic larvulae. Some species have stronger tendencies to migrate than others in this taxon. Explanations for the coincidence with mass movements of Naididae are not yet apparent.

The lack of winter data could be deceiving with regard to the absence or rarity of larger Crustacea. Intake forebay collections (Mozley 1973a) yielded mature male *Pontoporeia*, and 1974 winter fish larvae collections near the beach included *Mysis relicta*. Onshore migrations of these larger Crustacea in winter could lead to large amounts of midwinter benthos entrainment. Whether or not entrainment will be lethal to either summer or winter migrants, and if so, whether or not this will have a measureable impact on local populations remain to be seen.

SEASONAL CHANGES

Strong patterns of seasonal abundance were characteristic of *Pontoporeia* and Chironomidae, and Naididae in zone 0. Annual *Pontoporeia* reproduction, which caused early summer increases in population densities, was described by Alley (1968). At depths over 35 m, seasonality of reproduction and abundance was much less. The large increases in numbers of Chironomidae in shallow

water at the Cook Plant were also associated with reproduction, but in this case the animals were caught just prior to pupation and emergence as adults. From the egg to the last larval instar, the species which accounted for most of the seasonal fluctuations were so small that every individual escaped through the benthos screen. These were *Paracladopelma* cfr. *rolli*, *P. tylus* and *Parachironomus* cfr. *demeijerei*. Similar losses of early instars take place in rarer species, also, but have less impact on total Chironomidae numbers (e.g., *Potthastia* cfr. *longimanus* and *Monodiamesa tuberculata*). The larger species are retained on the screen in the last two instars, and consequently appear to fluctuate less in time (*Chironomus* and *Cryptochironomus* sp. 2).

The largest increases in abundance occur in early to mid-summer, and include less well-defined increases in the Tubificidae, also. This is somewhat later than the spring phytoplankton bloom in the nearshore area (Dr. E. F. Stoermer, personal communication). The relative effects of photoperiodism and temperature in controlling the rate of maturation and development is not known for species in the Cook area.

Absence of winter data leaves us in some uncertainty about reproduction and growth between November and April, but intake forebay collections when the Cook Plant becomes operable will provide insight into these processes. In general, total animals and individual taxa decline in abundance over winter, and early spring is the season of smallest population densities. From size-frequency data, it is clear that *Pontoporeia* matures and reproduces in mid-winter at the Cook Plant, just as it does in many other North American lakes and the Baltic Sea (Segerstråle 1971). The deeper stations at the Cook Plant are shallower than the approximate depth at which summer mating can occur regularly. Segerstråle (1971) indicates that the onset of gonad maturation is determined by decreasing day length in autumn.

The rate of development of the young *Pontoporeia* in brood chambers of the gravid females appears to be temperature-dependent. In 1972, the smallest size class first appeared in benthic zone 0 collections between the May and June surveys (Fig. 29), but in 1973 this class was already present before the April survey. Data on daily maximum and minimum temperatures at a depth of 12m from the St. Joseph, Michigan, city water intake a few kilometers north of the Cook survey area have been presented in earlier reports (Ayers, Soo and Yocum 1972; Ayers 1973). Those data were converted to degrees centigrade and the maximum and minimum for each day were averaged. The daily averages were summed over the period from January 1 of each year to the date of each survey in 1972 and 1973 to serve as an estimate of the cumulative thermal exposure of gravid females. In 1972, the sum was 301° before the May survey, and 659° by the June survey when the <3 mm size class was found in zone 1. In 1973, the sum was 418° before the April survey, and free-living young were already present in zone 1. These data suggest that a sum of about 350° is required for completion of development in the marsupium. If an area of bottom were heated to a constant 4°C throughout the winter, release of young could occur before April 1.

The effect of early release of young does not appear to have been very great for *Pontoporeia* abundance, since only small increases occurred from 1972 to 1973. Clearly, a wide range of natural variation in date of release occurs in the absence of artificial thermal influences. Despite the additional growing time, zone 1 *Pontoporeia* had not advanced beyond the second size class (3-5 mm) in July 1973 and so were at about the same stage of development as in July 1972. Other factors may limit growth of *Pontoporeia* besides temperature after release from the marsupium.

POTENTIAL EFFECTS OF THE COOK PLANT

Many data on numbers, sizes and kinds of zoobenthos have now been collected near the Cook Plant before it has begun to operate. Still, many questions remain about the extent of damage or stimulation which might occur among benthic animals, and about the spatial extent of the heated plume in winter, when it can become more dense than the unheated lake water. At this point, we can only speculate about some of the possibilities which could result, based on perhaps unrealistic projections of plume extent and effects.

The direct, erosive effect of the jet discharge on the bottom has been controlled by covering the area in front of the jets with large rocks (rip-rap). This has created a new benthic habitat which has attracted species of animals different from those living in the sand bottoms. The rock becomes colonized within weeks after any shutdown of the pumps, and will be scoured when they start up again. This is of little concern with regard to benthos of sand bottoms farther away, except possibly for increases in organic sedimentation, the remains of organisms such as *Cladophora* which would be scoured from the rip-rap.

The effects of a sinking plume are unlikely to be severe, for the temperature will be only a few degrees higher than ambient. This may accelerate development of affected organisms to some extent, and cause earlier maturation of Chironomidae or release of young *Pontoporeia*. Unless the sinking plume consistently flows over a particular area of bottom, even these effects would be so subtle that measurement would be difficult.

The most severe effects on benthos which are presently imaginable are those of entrainment of animals which occur above bottom. At certain times of year, large numbers of animals may pass through the condensers, particularly at night in midsummer, and perhaps in midwinter. Entrainment has not produced

very high mortalities of zooplankton (Industrial Biotest Laboratories, Inc. 1973), so entrained benthos may not necessarily be killed. Because of their size, however, which is small enough to allow passage through the traveling screens but large compared to most zooplankton, benthic animals may suffer much heavier mechanical damage during passage. The entrainment losses, even if important compared to the number entrained, could probably be replaced rapidly because of the high fecundity of most invertebrates. *Pontoporeia* carries about 20 eggs per gravid female (Juday and Birge 1927). Chironomidae lay several egg masses per female, each of which contains several hundred to several thousand eggs (Oliver 1971). Naididae reproduce readily by budding new individuals asexually from the caudal end of the body (Pennak 1953). If Naididae were completely eliminated by entrainment near the plant, the zoobenthic species assemblage might not be detectably different from July 1970, when no Naididae were collected.

The sensitivity of preoperational data to future changes is not very fine, for only increases of several multiples in observed abundance means would be statistically significant. Subtle effects of discharges or entrainment, causing lesser changes in numbers, will not be detectable, even if they occur. This is only partly due to the number of replicate observations available before operation, however, since even much larger amounts of replication would not have given appreciably better sensitivity.

When charged with the task of describing the benthic animals as thoroughly as appears necessary, it is difficult to determine whether or not it has been completed. The final test will be the ability to make an unequivocal statement that the plant has or has not affected the zoobenthos several years after operation begins. At this point, only the magnitude and types of changes which could be detected can be outlined. The essentially descriptive data

give some insight into the changes which occur naturally from year to year, and show some of the major seasonal fluctuations of the benthic animals. Little or no information of this type has been available from Great Lakes benthic habitats previously.

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THE PHYTOPLANKTON OF 1973

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Abstract. The results of monthly phytoplankton collections during April through October 1973 over a 7- or 8-station sampling grid in front of the Donald C. Cook Nuclear Station are reported and discussed. Intercomparisons between the abandoned Utermöhl method of phytoplankton counting and the more recent Settle-Freeze method, which was adopted in July 1973, show that greater percentages of phytoplankters can be identified to species by the Settle-Freeze method than by the Utermöhl method, though more cells per milliliter are counted by the latter method. A second settling and decantation in the Settle-Freeze method appears to be probable cause of fewer cells being found by Settle-Freeze; a longer settling time before decantation in Settle-Freeze method appears to be the remedy to most of the cell count difference between the methods, for the second settling and decantation is a basic difference between the methods. Cell counts at the Cook Plant stations during 1973 ranged from 106 to 6,198 cells/ml, but the great majority of them were in the 1,000 to 2,000 cells/ml range. Dominant forms in 1973 were the diatoms *Stephanodiscus minutus*, *S. tenuis*, *Melosira granulata* v. *angustissima* and *Fragilaria crotonensis* with flagellates appearing as a co-dominant in April. The diatom *Stephanodiscus tenuis* was heavily dominant in June when it comprised 59.7% of the phytoplankton population.

INTRODUCTION

During the field season of 1973, phytoplankton were collected monthly at 7 or 8 sampling stations in the immediate vicinity of the Cook Plant (the number

of stations sampled depending upon the presence or absence of heavy dredging equipment on the station location) and seasonally at 36 sampling stations in a grid ranging 7 miles south and 7 miles north as well as 7 miles offshore. The minimal monthly surveys were designed to give information on the temporal succession of species or groups, while the large seasonal surveys were designed to provide seasonal spatial distribution information and to be massive enough to capture rare forms that might not be taken in the limited monthly surveys, but which might be of value in assessing whether new forms were being added to the population.

This paper addresses only the minimal monthly surveys; the large seasonal surveys will be reported later. A brief, but important, part of this paper deals with intercomparisons between the more-or-less standard Utermöhl settling chamber and inverted microscope method of counting and identifying phytoplankton and the more recent Settle-Freeze method (Sanford, Sands, and Goldman 1969) which we adopted in July 1973.

METHODS

Figure 1 shows the collection stations designed to be used in the minimal monthly surveys during 1973. It was not possible to occupy all these stations in all months of the field season, because on the days when we could be there heavy construction equipment was on some of the station positions. Station DC-1 is so near the plant discharges area that our small boats could not safely be operated near it in the presence of heavy dredging equipment. Unexpectedly, station DC-0 proved to be unsamplable in April, July, and October because of the temporary (but real) presence of dredging barges anchoring there. Collections of phytoplankton were not made in November because bad weather (requiring

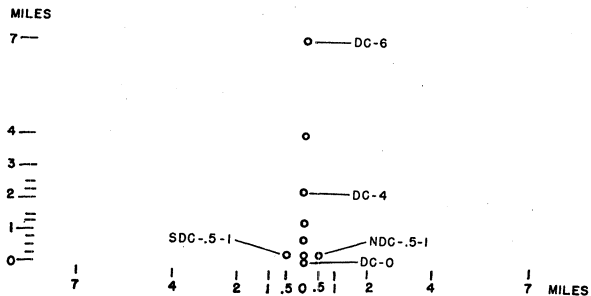


FIGURE 1. The minimal Cook Plant survey grid. Used in months between seasonal surveys.

staying in harbor) had exhausted the available time of the R/V MYGIS.

At all stations other than DC-0, collections were made by Niskin bottle at one meter of depth; at station DC-0 a liter brown polyethylene bottle was held by hand below the water surface until filled. All samples were of one liter volume and preserved with Utermöhl's iodine solution with 25 ml of glacial acetic acid per liter added.

After preliminary settling of the one liter samples, 900 ml of the supernatant liquid was siphoned off, and the remaining 100 ml swirled to resuspend the settled material. Of the latter, 18 ml were placed in a settling chamber, which has a mechanically held microscope slide as a floor, and settled for two days. The chamber was then very gently moved to set upon a block of dry ice until the bottom 2 or 3 ml of the water column were frozen. Removed from the dry ice, the chamber was allowed to thaw until it could be removed--leaving a wafer of ice and water on the slide. Dehydration was by placing the slide in a chamber of anhydrous alcohol vapor followed by a toluene vapor chamber. Cover glasses were attached with Permount.

In counting, a horizontal and a vertical row across the slide were counted and identified at 1000X under oil immersion on a Leitz Ortholux microscope.

RESULTS AND DISCUSSION

INTERCOMPARISONS OF UTERMÖHL AND SETTLE-FREEZE METHODS

Ten samples (from stations DC-0 and DC-2 collected on 17 May 1973, and from stations DC-3, DC-4, DC-6, NDC-.5-2, SDC-.5-2, SDC-1-0, SDC-4-3, and SDC-7-5 taken on 25 April 1973) were used in the intercomparisons. Each sample was processed for identifications and counts of cells/ml by both the Utermöhl

settling chamber and inverted microscope method and by the Settle-Freeze method.

Comparisons made between the two methods were: 1) number of forms identified to species, 2) total number of forms recognized, 3) percent of forms identified to species, and 4) numbers of cells/ml. These comparisons are presented in Table 1.

Also made were comparisons of percentages of the population and of cell counts represented by each of the major algal groups. These are given in Table 2.

Table 1 shows that higher numbers of taxa were identified to species when the Settle-Freeze method was used (a mean number of 34.9 taxa vs. 28.7 by the Utermöhl method). The mean number of total forms recognized by each method was 46.5. The Settle-Freeze method allowed a mean of 75.2% of all forms to be identified to species, while a mean of 61.6% were identified to species using the Utermöhl method. Mean numbers of cells counted were higher by the Utermöhl method, as was pointed out by Sanford et al. (1969), who implied a somewhat greater efficiency of the Utermöhl method. It is our belief that loss of cells occurs in the decantation of the freezing chamber after freezing because settling has not been complete. We propose to avoid this by increasing the settling time before freezing.

According to Table 1 of Sanford et al., the relative numbers of total cells counted in the two methods were about 13 by the Utermöhl to 10 by Settle-Freeze, or a ratio of 1.0 to 1.3. The ratio of our present mean cell counts (Table 1) is 1.00 to 1.86; this is also the ratio of total cells counted as cells per liter in the same ten samples in Table 2.

Our 1.00 to 1.86 ratio of total cells counted in the same ten samples by the two methods contains, in addition to the apparent 1.3 greater efficiency

TABLE 1. Intercomparisons of the Utermöhl settling chamber method and the Settle-Freeze method at ten 1973 stations.

Station	Method	# of forms identified to species	Total forms recognized	% of forms identified to species	Cells/ml
DC-0	U	29	44	65.9	2,923
DC-2	U	39	56	69.6	3,737
DC-3	U	26	46	56.5	2,335
DC-4	U	25	43	58.1	2,344
DC-6	U	28	42	66.7	3,005
NDC-.5-2	U	27	45	60.0	2,476
SDC-.5-2	U	29	46	63.0	2,958
SDC-1-0	U	33	57	57.9	1,550
SDC-4-3	U	25	43	58.1	2,103
SDC-7-5	U	<u>26</u>	<u>43</u>	<u>60.5</u>	<u>2,264</u>
		Mean 28.7	Mean 46.5	Mean 61.6%	Mean 2,570 C/ml
DC-0	S-F	32	48	66.7	1,187
DC-2	S-F	37	52	71.2	1,643
DC-3	S-F	39	53	73.6	1,816
DC-4	S-F	26	34	76.5	1,122
DC-6	S-F	43	53	81.1	1,005
NDC-.5-2	S-F	37	47	78.7	1,261
SDC-.5-2	S-F	35	48	72.9	1,094
SDC-1-0	S-F	37	47	78.7	2,958
SDC-4-3	S-F	30	38	78.9	845
SDC-7-5	S-F	<u>33</u>	<u>45</u>	<u>73.3</u>	<u>921</u>
		Mean 34.9	Mean 46.5	Mean 75.2%	Mean 1,385 C/ml

TABLE 2. Comparison of the Settle-Freeze and Utermöhl methods by major algal groups. Ratio # S-F to UC = 1.00:1.86.

Major Groups	Percent by		Cells per liter by	
	<u>S-F</u>	<u>UC</u>	<u>S-F</u>	<u>UC</u>
Cocccoid blue-greens	0.39	0.19	53,800	48,230
Filamentous blue-greens	0.38	1.05	52,407	270,810
Cocccoid greens	4.16	0.30	573,231	76,055
Filamentous greens	0.14	0.15	18,551	39,415
Flagellates	20.93	29.71	2,883,949	7,631,540
Centric diatoms	46.84	45.14	6,454,320	11,593,775
Pennate diatoms	25.81	17.41	3,555,996	4,473,905
Desmids	0	0.04	0	9,275
Other algae	<u>1.35</u>	<u>6.01</u>	<u>186,444</u>	<u>1,543,825</u>
Total	100.00	100.00	13,778,698	25,686,830
Total blue-greens	0.77	1.24	106,207	319,040
Total greens (including flagellates, desmids and others)	26.58	36.21	3,662,175	9,300,110
Total diatoms	<u>72.65</u>	<u>62.55</u>	<u>10,010,316</u>	<u>16,067,680</u>
Total	100.00	100.00	13,778,698	25,686,830

of the Utermöhl method, a component of "operator difference" which is always present and which varies from operator (phytoplankton analyst) to operator and is heavily dependent upon operator experience. In this case, the Utermöhl counts were made by a PhD with eight years' experience, much of it using the

Utermöhl method; the Settle-Freeze counts were made by a Bachelor of Science with three years' experience, none of it with the Utermöhl method. To give the latter operator eight years of experience with the Utermöhl method was impossible, and the more experienced operator was the only one available who could use the Utermöhl method. When these two operators were compared on the same Settle-Freeze materials, the more experienced one would consistently count about one and one-half times as many cells as the less experienced. Our present 1.00 to 1.86 ratio of total cells counted is, then, not a true comparison of the efficiencies of the two methods, but contains a reflection of the fact that we had to make use of the last operator who could use the abandoned Utermöhl method.

All aspects being considered, we believe that the advantages of the Settle-Freeze method are: 1) permanent slides suitable for re-study are produced, and 2) more forms being identifiable to species outweigh fewer cells being counted.

STATISTICAL COMPARISON OF THE UTERMÖHL AND SETTLE-FREEZE METHODS

One water sample from each of the ten stations was divided, and part was counted by each of the two methods. This gave ten pairs of values for the cells/ml. We wanted to know if the mean cells/ml obtained with the Utermöhl method was significantly different from the mean cells/ml obtained with the Settle-Freeze method. These data were analyzed using a t-test for paired comparisons (Sokal and Rohlf 1969, p. 332). The test was performed on cells/ml and also on two other quantities: the number of forms identified to species in each sample, and the total number of forms recognized in each sample. (A form is either a species, a genus, or a broader category; not all cells can be identified to species with these methods.) The mean values and the results of the three t-tests are shown below.

N = 10 (no. of pairs of values considered in each test)

<u>Test No.</u>	<u>Variable</u>	<u>Mean value with Utermöhl</u>	<u>Mean value with S-F</u>	<u>Difference</u>	<u>t</u>
1	Cells/ml	2569.5	1385.2	1184.3	3.65**
2	No. of forms identified to species	28.7	34.9	-6.2	3.72**
3	Total no. of forms recognized	46.5	46.5	0.0	0.0 n.s.

n.s. Not significant
 ** Significant, $p < .01$

$t_{.05 [9]} = 2.26$

$t_{.01 [9]} = 3.25$

The results show that, for these ten water samples, the Utermöhl method gave a significantly higher value of cells/ml than the Settle-Freeze method, but a significantly lower number of forms identified to the species level. The total number of forms recognized was not significantly different with the two methods. The Settle-Freeze method thus appears to permit better identification of the actual species present. This may be due to the replacement of water with a non-aqueous mounting medium, giving better resolution under the microscope.

It should be noted that each method was applied by a different technician. It would have been preferable to run both methods with both technicians, but this was not convenient since one of them was trained in only a single technique. A further refinement could have resulted if each sample had been counted more than once with each method. We did not judge this refinement to be worth the additional counting time required.

As a test of the seriousness of fewer cells being counted by Settle-Freeze,

Table 2 was prepared. It gives a comparison of the two methods by their success in finding the major algal groups. Although there is variability in the results, the table demonstrates that no group occurring in abundance of 1% or more of the population will be missed.

THE PHYTOPLANKTON OF 1973

During the seven months of sampling, 238 species or groups of phytoplankters were collected in the short surveys. They are listed alphabetically in Table 3 and are annotated as being abundant, rare, and riverine. "Abundant" was arbitrarily set at 100 or more cells taken during the seven months of collections. The table also gives the total numbers and months of occurrence of the rare species or groups.

In the collections of 1973 there were 50 forms (species or groups) which deserved "abundant" ratings. These are presented by stations and months in Table 4. The 50 abundant forms in 1973 (compared to 32 so ranked in 1972) are considered to be, in part at least, a reflection of the greater specificity made possible by the Settle-Freeze method. Three species, *Coccomyxa minor*, *Fragilaria construens*, and *Schroederiella papillata*, were not included in the "abundant" tabulation because they exceeded 100 cells once in one collection and were not present in any other samples.

Four forms, *Rhizosolenia gracilis*, *Rhizosolenia longiseta*, *Rhizosolenia* spp. (unidentified), and *Synedra ulna*, which had been abundant in 1972 did not accumulate to 100 cells in the 1973 collections, though they were by no means absent.

Nitzschia spp. (all species combined) has been included as an abundant genus to show its substantial presence, though none of its species attained to this rank individually.

TABLE 3. Master species list, 1973, indicating "Abundant," "Rare," and "riverine" by A, R and r on the left.

Species		Total monthly collections of rare forms at all stations
R	<i>Achnanthes clevei</i>	Oct 2
R	<i>A. clevei</i> v. <i>rostrata</i>	Sep 2, Oct 2
R	<i>A. lanceolata</i>	Aug 4
R	<i>A. lanceolata</i> v. <i>dubia</i>	May 2, Jun 2
R	<i>A. laterostrata</i>	Sep 3
R	<i>Achnanthes</i> spp.	May 1, Aug 2, Sep 9
R	<i>Actinastrium hantzschii</i> v. <i>fluviale</i>	Jul 63, Aug 15
R	<i>Amphipleura pellucida</i>	Apr 2, Aug 6, Sep 25, Oct 4
R(r)	<i>Amphora ovalis</i>	Jun 2, Aug 2, Sep 5
R(r)	<i>Amphora ovalis</i> v. <i>libyca</i>	Sep 10, Oct 5
R(r)	<i>A. ovalis</i> v. <i>pediculus</i>	Sep 9
R(r)	<i>Amphora</i> spp.	Jun 2, Jul 2, Aug 11, Sep 12
A	<i>Anabaena</i> spp.	
A	<i>Anacyctis</i> spp.	
R	<i>Ankistrodesmus falcatus</i>	Apr 30, May 1, Jun 4, Aug 5, Sep 5, Oct 28
R	<i>A. falcatus</i> v. <i>mirabilis</i>	Apr 13
R	<i>A. golifastum</i>	Apr 6, Jul 14, Aug 17, Oct 4
R	<i>Ankistrodesmus</i> sp. #1	Apr 35, May 4, Jul 4, Sep 10, Oct 9
R	<i>Ankistrodesmus</i> sp. #2	Jul 4
R	<i>Ankistrodesmus</i> sp. #3	Apr 16, May 2, Jul 4, Oct 9
R	<i>Ankistrodesmus</i> sp. #5	Jul 7, Oct 6
A	<i>Ankistrodesmus</i> spp.	
R	<i>Aphanizomenon flos-aquae</i>	Jun 2
R	<i>Aphanizomenon</i> spp.	Apr 17
R	<i>Asterionella bleakeleyi</i>	May 4
A	<i>A. formosa</i>	
R	Blue-green colonies	Aug 10, Oct 3
R	Blue-green filaments	Apr 38, May 12
R	Blue-green cells	Aug 10
R	<i>Borodinella polytetras</i> (colonies)	Jul 4
R	<i>Caloneis ventricosa</i>	Sep 5
R	<i>C. ventricosa</i> v. <i>truncatula</i>	Jun 2
R	<i>Caloneis</i> spp.	Jul 2
R	<i>Ceratium hirundinella</i>	Aug 7, Sep 8, Oct 1
R	<i>Chaetopeltis orbicularis</i> (colonies)	Jul 2
R	<i>Characium limneticum</i>	Aug 2, Oct 2
A	<i>Chlamydomonas</i> spp.	
A	<i>Chlorococcum humicola</i>	May 1
A	<i>Chroococcus</i> spp. (mostly <i>limneticus</i>)	
R	<i>Closteropsis longistoma</i>	Apr 3
R	<i>Closterium</i> spp.	Oct 2
R	<i>Cocconeis placentula</i>	Aug 2
R	<i>C. placentula</i> v. <i>evglypta</i>	Aug 4
R	<i>Cocconeis</i> spp.	May 2
R	<i>Coelastrum ephraerium</i>	Jul 1, Aug 12, Sep 2, Oct 2
R	<i>Coelastrum</i> spp.	Jun 2, Jul 10, Aug 2, Sep 2, Oct 2
R	<i>Coelosphaerium megallianum</i>	Oct 3
R	<i>Coelosphaerium</i> spp.	Aug 2
R	<i>Coemmarium</i> spp.	Jul 7, Sep 4, Oct 3
R	<i>Crucigenia apiculata</i>	Sep 2
R	<i>C. quadrata</i>	Jun 2, Aug 34, Sep 10, Oct 30
R	<i>C. rectangularis</i>	Jun 7
R	<i>C. truxata</i>	Jul 30
R	<i>Crucigenia</i> spp.	Oct 4
R	<i>Cryptomonas</i> spp.	

TABLE 3 continued.

A	<i>Cyclotella atomus</i>	
R	<i>C. oompa</i>	Jun 2, Jul 5, Aug 16, Sep 43, Oct 23
A	<i>C. cryptica</i>	
R	<i>C. glomerata</i>	Apr 20, May 6
A	<i>C. kuetzingiana</i>	
R(r)	<i>C. meneghiniana</i>	May 27, Jun 15, Jul 38, Aug 7, Oct 12
R(r)	<i>C. meneghiniana</i> v. <i>plana</i>	Jul 2, Oct 2
A	<i>C. mitiganiana</i>	
A	<i>C. ocellata</i>	
R	<i>C. pseudostelligera</i>	Apr 4, Jun 25
A	<i>C. stelligera</i>	
R	<i>C. temperci</i>	Apr 1
A	<i>Cyclotella</i> spp.	
R	<i>Cymbella</i> spp.	May 4, Jun 2, Aug 4, Sep 6
R	<i>Cymatopleura solea</i>	Apr 3, May 8
R	<i>Dactylococcopsis</i> spp.	
R	<i>Diatoma tenue</i>	Apr 8, May 4, Jul 2, Aug 2, Oct 5
A	<i>D. tenue</i> v. <i>elongatum</i>	Jun 3
R	<i>D. tenue</i> v. <i>pachycephala</i>	Apr 10, May 3, Sep 2, Oct 2
R	<i>D. vulgare</i>	Jun 1
R	<i>Dietyosphaerium pulchellum</i>	Sep 2
R	<i>Dietyosphaerium</i> spp.	May 28
R	<i>Dimorphococcus</i>	Oct 15
A	<i>Dinobryon bavaricum</i>	
A	<i>D. divergens</i>	
R	<i>D. sociale</i>	Jun 72, Jul 2, Oct 2
R	<i>Dinobryon</i> spp.	Apr 6
A	<i>Dischlagellates</i>	
R	<i>Elakototrix gelatinosa</i>	Aug 2
R	<i>Euglena</i> spp.	May 9
A	<i>Flagellates</i>	
A	<i>Fragilaria brevistriata</i>	Oct 1
A	<i>F. capucina</i>	
A	<i>F. construens</i> v. <i>parvula</i>	Oct 2
R	<i>F. construens</i> v. <i>venter</i>	May 2
A	<i>F. crotenensis</i>	
A	<i>F. intermedia</i>	
R	<i>F. pinnata</i>	Jul 5, Sep 12
A	<i>Glenodinium</i> spp.	
A	<i>Gloecocystis planktonica</i>	
A	<i>Gloecocystis</i> spp.	
R	<i>Gomphonema</i> spp.	Sep 3
R	<i>Gomphosira lacustris</i> v. <i>compacta</i>	Sep 5, Oct 5
R	<i>Gomphosira</i> spp.	Sep 19, Oct 4
R	<i>Gonium sociale</i>	Aug 7
A	Green colonies	
R	Green filaments	Apr 14, May 9, Oct 4
R	<i>Kirchneriella</i> spp.	Jul 59, Aug 2, Oct 8
R	<i>Mallomonas</i> spp.	Jun 4, Jul 5, Aug 8, Sep 2, Oct 2
R	<i>Marenotella elegans</i> (colony)	Jul 22, Aug 11
R	<i>Melosira ambigua</i>	Oct 3
R	<i>M. distans</i> v. <i>alpigena</i>	Aug 2
A(r)	<i>M. granulata</i>	
A(r)	<i>M. granulata</i> v. <i>angustissima</i>	
A	<i>M. islandica</i>	
A	<i>M. italica</i>	
R	<i>M. urticae</i>	May 6, Sep 4
R	<i>Meridion circulare</i>	Jul 2
R	<i>Merismopodia</i> spp.	Aug 5, Sep 4, Oct 2
R	<i>Microcystis aeruginosa</i>	May 1, Jul 5, Sep 3

TABLE 3 continued.

R	<i>Microcystis</i> spp.	Aug 69, Oct 3
R	<i>Mougeotia</i> spp.	Jun 2
R(r)	<i>Navicula capitata</i>	Apr 2, Jun 2
R	<i>N. clementis</i> v. <i>quadristigmata</i>	Apr 2
R(r)	<i>N. costulata</i>	Jul 2, Aug 4, Sep 4
R(r)	<i>N. decussis</i>	Jun 4
R	<i>N. lanceolata</i>	Apr 1
R	<i>N. latens</i>	Apr 2
R	<i>N. meniscus</i> v. <i>upsalensis</i>	Sep 3
R	<i>N. pupula</i>	Oct 2
R	<i>N. triplanotata</i>	May 10, Sep 2
R(r)	<i>Navicula</i> spp.	Apr 2, May 6, Jun 11, Jul 4, Aug 71, Sep 26
R	<i>Neidium dubium</i> v. #1	May 2
R	<i>Neidium</i> spp.	Sep 6
R(r)	<i>Nitzschia acicularis</i>	Apr 6, May 8, Jul 4, Aug 2, Sep 55, Oct 18
R	<i>N. acuta</i>	Apr 2, May 3
R	<i>N. amphibia</i> v. <i>fossilis</i>	May 6, Oct 1
R	<i>N. bacata</i>	Apr 28, May 15, Oct 1
R	<i>N. capitellata</i>	Apr 4, Aug 2
R	<i>N. confinis</i>	Apr 9, May 4, Jul 11, Aug 6, Sep 10, Oct 18
R	<i>N. dissipata</i>	Apr 5, May 9
R	<i>N. fonticola</i>	Oct 5
R	<i>N. fonticola</i> v. <i>pelagica</i>	May 2, Aug 2
R	<i>N. gracilis</i>	Aug 2
R	<i>N. holsatica</i>	Aug 22
R	<i>N. hungarica</i>	Apr 2, Jul 1
R	<i>N. linearis</i>	Jun 2
R	<i>N. palea</i>	Apr 14, May 6, Jul 2, Aug 4, Sep 9, Oct 16
R	<i>N. paleacea</i>	Jul 11, Sep 3, Oct 4
R	<i>N. pseudoatomus</i>	May 2
R	<i>N. rostrata</i>	Apr 7, Sep 5
R	<i>N. sigma</i>	Apr 2, May 2
R	<i>N. spiculoides</i>	Apr 6, May 6, Oct 1
R	<i>N. tryblionella</i>	May 2
R	<i>N. species #1</i>	May 4, Oct 4
R(r)	<i>N. species #2</i>	Apr 19, May 19
R	<i>N. species #10</i>	Oct 1
R	<i>N. species #12</i>	Apr 2
R	<i>N. species #20</i>	Oct 1
A(r)	<i>Nitzschia</i> spp. (all, combined)	
R	<i>Oestrupia zachvatkini</i>	Aug 4
A	<i>Oocystis</i> spp.	
A	<i>Oscillatoria</i> spp.	Jun 2
R	<i>Pediastrum boryanum</i>	Jun 2, Jul 2, Aug 2, Oct 7
R	<i>P. duplex</i>	
R	<i>P. duplex</i> v. <i>gracillimum</i>	Oct 1
R	<i>P. duplex</i> v. <i>reticulatum</i>	Sep 2
R	<i>P. simplex</i>	Oct 1
R	<i>P. tetras</i>	Oct 3
R	<i>Pediastrum</i> spp.	Aug 2
R	<i>Phacus</i> sp.	Apr 1
R	<i>Phormidium</i> spp.	May 1, Jun 37, Aug 3, Sep 2
R	<i>Pinnularia</i> spp.	Sep 4
R	<i>Quadrigula lacustris</i>	May 1, Jun 14, Sep 8, Oct 1
A	<i>Rhizosolenia eriensis</i>	
R	<i>R. gracilis</i>	Apr 21, May 17
R	<i>R. longicauda</i>	May 31, Sep 3, Oct 3
K	<i>Rhizosolenia</i> spp.	Sep 12
R	<i>Rhizosolenia curvata</i>	Apr 2, Jul 2
R	<i>Scenedesmus abundans</i>	Jun 5, Aug 8

TABLE 3 continued.

R	<i>S. acuminatus</i>	Oct 2
R	<i>S. acutiformis</i>	Jun 2
A	<i>S. bioellularis</i>	
R	<i>S. bifuga</i>	Oct 2
R	<i>S. denticulatus</i>	Jul 7, Oct 2
R	<i>S. dimorphus</i>	Jul 2, Aug 14, Sep 18, Oct 55
R	<i>S. eozonis</i>	Aug 17
R	<i>S. falcatus</i>	Jul 22, Aug 35, Sep 7, Oct 18
R	<i>S. inornatus</i>	Jun 3, Jul 2, Oct 8
R	<i>S. opolienensis</i>	May 11, Jul 4, Aug 7
R	<i>S. opolienensis v. contracta</i>	Jun 4
A	<i>S. quadricauda</i>	
R	<i>S. quadricauda v. longispina</i>	Jul 52, Sep 2, Oct 13
R	<i>S. serratus</i>	Jul 7, Oct 11
R	<i>S. tenuispina</i>	May 3
R	<i>S. wisconsinensis</i>	Jul 7, Oct 7
A	<i>Scenedesmus</i> spp. (all, combined)	
	<i>Schroederiella papillata</i>	
R	<i>Selenastrum</i> sp.	Aug 3
R	<i>Sphaerocystis schroeteri</i>	Jul 15, Aug 8, Oct 3
R	<i>Sphaerocystis</i> sp.	Jul 2
R	<i>Staurastrum</i> spp.	Jul 7, Aug 4, Oct 2
A	<i>Stephanodiscus alpinus</i>	
R	<i>S. astraea</i>	Apr 2, May 3, Sep 3, Oct 2
A	<i>S. binderanus</i>	
A	<i>S. hantzschii</i>	
A	<i>S. minutus</i>	
R	<i>S. niagarae</i>	Apr 4, May 3, Oct 1
R	<i>S. niagarae v. magnifica</i>	May 1
A	<i>S. subtilis</i>	
A	<i>S. tenuis</i>	
R	<i>S. transilvanicus</i>	Apr 33, May 4, Jun 2, Aug 4, Sep 5, Oct 1
A	<i>Stephanodiscus</i> spp. (unidentified)	
R	<i>Surirella angustata</i>	Apr 1, May 8, Oct 6
R	<i>S. ovata v. pinnata</i>	Sep 2
R	<i>Synedra acus</i>	Apr 2, May 1, Jul 3, Aug 35, Sep 2, Oct 4
R	<i>S. deltoatissima</i>	May 1, Jun 40, Jul 2, Aug 9, Sep 14, Oct 30
A	<i>S. deltoatissima v. angustissima</i>	
R	<i>S. demeraras</i>	Sep 5
R	<i>S. fasciculata</i>	Apr 3
A	<i>S. filiformis</i>	
R	<i>S. menisculus</i>	Apr 2, May 4
A	<i>S. ostenfeldii</i>	
R	<i>S. parasitica</i>	Sep 12
R	<i>S. rumpens</i>	May 3
R	<i>S. tenera</i>	Apr 20, May 6
R(x)	<i>S. ulna</i>	Apr 2, May 4, Jun 4, Aug 8, Sep 7
R	<i>S. ulna v. chaeana</i>	Apr 10, May 24, Jun 2, Jul 2, Oct 2
R	<i>S. ulna v. danica</i>	Sep 2
R	<i>Synedra</i> spp.	Apr 16, May 21, Jun 51
A	<i>Tabellaria fenestrata</i>	
R	<i>T. fenestrata v. geniculata</i>	Apr 33
A	<i>T. flocculosa</i>	
R	<i>Tetradron caudatum</i>	Jul 6
R	<i>T. caudatum v. longispinum</i>	Jul 2
R	<i>T. minimum</i>	Jul 2, Oct 3
R	<i>T. pentadricum</i>	Oct 2
R	<i>T. trigonum</i>	Jul 2
R	<i>T. tridulum</i>	Jul 2
R	<i>Tetradron</i> spp.	Jul 12, Oct 4
R	<i>Tropidoneis lepidoptera v. proboscidea</i>	Aug 4
R	<i>Ulothrix</i> spp.	Sep 4, Oct 3
R	<i>Westella linearis</i>	Aug 7

TABLE 4. The 50 abundant phytoplankton forms in the 1973 Cook Plant collections, by stations and months. Dashes indicate that collections were not made.

Anabaena spp.

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	0	0	0	0
May	0	0	0	--	0	0	0	0	0
Jun	2	0	0	--	0	0	0	0	0
Jul	15	0	--	--	15	4	2	2	5
Aug	3	2	0	--	2	3	5	0	3
Sep	3	3	0	--	2	0	2	0	7
Oct	13	9	--	--	7	20	3	5	4

Anacystis spp.

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	17	0	0	0
May	0	0	0	--	0	0	0	0	0
Jun	0	0	0	--	0	0	0	0	0
Jul	0	2	--	--	0	0	2	0	2
Aug	0	0	4	--	2	7	15	0	25
Sep	0	2	2	--	7	2	26	3	8
Oct	12	0	--	--	15	2	0	2	6

Ankistrodesmus spp.

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	27	45	--	--	13	9	2	3	9
May	0	0	4	--	0	0	5	1	0
Jun	0	2	3	--	3	5	4	8	0
Jul	28	7	--	--	13	0	0	0	0
Aug	2	2	0	--	3	2	0	17	0
Sep	3	2	2	--	3	7	5	2	2
Oct	7	17	--	--	8	7	12	2	2

TABLE 4 continued.

Asterionella formosa

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	30	33	--	--	54	109	11	32	20
May	0	3	0	--	63	24	2	9	12
Jun	23	0	7	--	5	28	50	120	125
Jul	7	0	--	--	22	0	17	1	0
Aug	18	33	68	--	0	0	12	46	5
Sep	75	126	377	--	154	122	79	121	33
Oct	88	46	--	--	23	3	0	2	16

Chlamydomonas spp.

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	0	0	0	0
May	0	0	0	--	0	0	0	0	66
Jun	10	53	31	--	46	124	0	127	65
Jul	0	292	--	--	0	0	140	17	191
Aug	247	0	139	--	248	497	257	0	309
Sep	0	87	613	--	88	0	159	240	215
Oct	134	0	--	--	276	197	0	0	60

Chroococcus spp. (mostly limneticus)

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	0	0	0	0
May	0	0	0	--	4	0	0	1	1
Jun	0	0	0	--	0	0	11	2	2
Jul	0	10	--	--	11	16	2	8	7
Aug	20	80	15	--	7	26	46	160	53
Sep	134	23	27	--	31	132	50	26	25
Oct	12	24	--	--	25	20	34	42	46

TABLE 4 continued.

Cryptomonas spp.

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	9	--	--	4	15	7	13	7
May	28	8	35	--	37	11	11	7	0
Jun	2	2	2	--	0	2	4	5	7
Jul	4	24	--	--	0	0	3	5	2
Aug	26	19	26	--	0	25	63	32	46
Sep	6	10	63	--	10	11	26	17	35
Oct	50	9	--	--	45	65	14	9	33

Cyclotella atomus

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	4	0	1	3
May	0	0	0	--	0	0	0	0	0
Jun	0	0	0	--	0	0	0	0	0
Jul	0	0	--	--	0	11	12	0	225
Aug	0	0	0	--	0	0	0	0	0
Sep	3	0	0	--	0	9	0	5	0
Oct	0	0	--	--	0	2	0	1	0

Cyclotella cryptica

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	2	0	--	--	6	0	0	1	4
May	3	0	0	--	9	4	2	0	0
Jun	0	0	0	--	0	0	4	0	0
Jul	19	0	--	--	32	0	0	0	0
Aug	0	6	0	--	2	0	0	13	0
Sep	0	0	7	--	3	0	5	3	0
Oct	5	13	--	--	5	8	2	1	0

TABLE 4 continued.

Cyclotella kutziana

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	2	6	2	2	7
May	8	0	0	--	0	2	4	3	7
Jun	2	0	3	--	0	8	15	0	7
Jul	4	0	--	--	17	9	3	0	1
Aug	3	15	60	--	2	3	5	6	0
Sep	0	7	24	--	0	0	2	13	0
Oct	0	0	--	--	5	3	2	4	0

Cyclotella michiganiana

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	4	2	--	--	0	2	2	1	7
May	6	0	2	--	7	6	2	1	0
Jun	2	0	0	--	2	0	19	2	0
Jul	4	27	--	--	32	3	10	1	12
Aug	7	4	11	--	5	8	0	9	0
Sep	19	5	12	--	3	6	3	0	2
Oct	12	4	--	--	3	5	4	6	3

Cyclotella ocellata

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	6	2	--	--	0	4	0	0	1
May	11	0	4	--	0	0	1	1	1
Jun	7	10	0	--	2	2	2	22	25
Jul	0	9	--	--	0	0	0	0	2
Aug	2	0	26	--	10	3	3	0	2
Sep	6	30	71	--	13	20	10	25	7
Oct	10	0	--	--	5	5	0	1	0

TABLE 4 continued.

Cyclotella stelligera

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	20	20	--	--	13	30	20	11	52
May	19	8	4	--	7	9	5	3	10
Jun	45	38	55	--	46	25	85	89	362
Jul	373	338	--	--	497	311	169	51	123
Aug	5	39	30	--	8	18	5	28	0
Sep	3	3	27	--	3	11	0	5	2
Oct	0	0	--	--	0	0	2	6	0

Cyclotella spp.

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	7	9	--	--	11	15	28	10	45
May	36	8	6	--	13	19	6	1	20
Jun	8	18	43	--	35	23	6	28	175
Jul	373	627	--	--	436	3	70	10	35
Aug	132	32	241	--	141	66	98	15	25
Sep	0	68	217	--	45	6	61	84	38
Oct	83	9	--	--	23	61	3	5	31

Diatoma tenue v. *elongatum*

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	2	--	--	4	4	0	1	1
May	3	3	13	--	4	17	2	2	10
Jun	0	3	5	--	7	5	0	5	0
Jul	0	2	--	--	2	0	0	0	0
Aug	0	2	0	--	0	0	0	0	0
Sep	14	5	22	--	3	11	12	5	7
Oct	3	2	--	--	8	2	0	0	0

TABLE 4 continued.

Dinobryon bavaricum

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	--	--	0	0	0	0	0
May	0	0	0	--	0	0	0	0	0
Jun	8	22	5	--	38	66	72	114	13
Jul	0	0	--	--	0	0	0	0	0
Aug	0	0	0	--	0	0	0	0	0
Sep	0	0	0	--	0	0	0	0	0
Oct	0	0	0	--	0	0	0	0	2

Dinobryon divergens

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	--	--	0	0	0	0	0
May	0	0	0	--	0	0	0	0	1
Jun	13	127	13	--	129	131	24	86	0
Jul	0	5	--	--	0	6	20	1	6
Aug	0	2	0	--	0	2	0	0	0
Sep	19	3	29	--	28	22	28	0	12
Oct	13	0	--	--	8	5	7	7	24

Dinoflagellates

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	2	2	--	--	2	2	0	5	2
May	3	0	6	--	2	4	0	0	0
Jun	0	0	0	--	0	0	0	0	0
Jul	0	2	--	--	18	3	0	0	0
Aug	2	9	4	--	2	2	0	15	7
Sep	0	0	2	--	0	0	0	0	2
Oct	5	4	--	--	0	0	2	0	0

TABLE 4 continued.

Flagellates

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	340	297	--	--	406	219	310	283	239
May	206	117	371	--	82	156	87	31	9
Jun	22	56	18	--	40	51	45	13	20
Jul	89	7	--	--	89	13	2	0	2
Aug	43	135	23	--	58	51	23	332	3
Sep	28	23	51	--	25	85	28	26	7
Oct	116	93	--	--	169	199	208	360	111

Fragilaria capucina

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	0	0	0	0
May	50	217	147	--	369	17	242	50	0
Jun	0	0	16	--	0	0	0	3	0
Jul	0	0	--	--	0	0	0	0	0
Aug	0	4	0	--	0	0	5	0	0
Sep	0	0	246	--	0	0	0	0	0
Oct	20	0	--	--	0	0	0	0	0

Fragilaria crotonensis

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	4	32	--	--	6	119	24	30	5
May	58	14	52	--	0	6	4	23	66
Jun	22	15	17	--	33	17	20	7	36
Jul	43	110	--	--	145	6	109	0	2
Aug	200	282	357	--	91	372	199	202	5
Sep	211	449	1329	--	238	252	228	159	189
Oct	268	2	--	--	56	167	63	22	46

TABLE 4 continued.

Fragilaria intermedia

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	26	0	--	--	17	48	0	7	11
May	8	0	56	--	0	74	5	29	3
Jun	0	0	0	--	22	0	0	0	0
Jul	0	0	--	--	0	0	0	0	0
Aug	7	0	105	--	0	0	5	0	0
Sep	0	0	0	--	0	0	0	0	0
Oct	0	0	--	--	0	15	0	0	0

Glenodinium spp.

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	6	15	--	--	4	11	11	6	4
May	0	0	4	--	0	4	0	1	0
Jun	0	0	0	--	0	0	4	0	0
Jul	13	0	--	--	11	1	0	0	0
Aug	0	2	0	--	0	0	0	6	0
Sep	0	0	0	--	0	0	0	0	0
Oct	0	0	--	--	0	0	0	0	0

Gleocystis planktonica

		cells/ml							
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	80	0	--	--	0	0	7	0	0
May	0	0	0	--	0	22	23	19	0
Jun	0	0	0	--	0	0	0	0	0
Jul	0	0	--	--	0	21	0	3	13
Aug	0	0	0	--	0	2	0	0	0
Sep	0	0	0	--	0	0	0	0	0
Oct	33	0	--	--	25	25	0	0	0

TABLE 4 continued.

Gloeocystis spp.

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	13	22	--	--	59	35	82	24	7
May	122	56	50	--	26	54	15	46	1
Jun	3	2	0	--	0	7	22	0	0
Jul	334	40	--	--	464	25	13	0	31
Aug	12	70	11	--	10	26	33	186	33
Sep	39	25	15	--	13	17	5	3	5
Oct	0	224	--	--	0	0	18	42	4

Green cells

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	113	7	--	--	0	0	0	0	0
May	19	3	7	--	4	9	6	1	0
Jun	0	0	0	--	0	0	0	0	0
Jul	35	0	--	--	93	4	42	0	10
Aug	0	0	23	--	0	31	13	67	10
Sep	0	0	0	--	0	0	0	0	0
Oct	0	37	--	--	0	0	0	0	0

Green colonies, undetermined (coccoid)

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	4	0	0	0
May	0	0	0	--	0	0	0	0	2
Jun	2	7	0	--	18	0	15	2	0
Jul	11	50	--	--	43	4	5	0	3
Aug	12	0	0	--	15	10	5	11	0
Sep	0	0	10	--	0	0	3	8	2
Oct	0	0	--	--	0	2	0	0	1

TABLE 4 continued.

Melosira granulata

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	12	--	--	15	13	6	8	9
May	159	25	22	--	171	178	4	0	7
Jun	7	0	78	--	13	45	7	28	0
Jul	275	216	--	--	525	0	2	0	0
Aug	144	139	568	--	136	122	83	83	0
Sep	67	33	68	--	58	28	10	0	0
Oct	36	375	--	--	7	31	48	34	0

Melosira granulata v. angustissima

cells/ml									
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	0	0	0	0
May	0	0	0	--	4	0	0	0	7
Jun	45	41	79	--	5	65	0	30	0
Jul	11	1015	--	--	6	0	0	0	0
Aug	1011	74	2945	--	420	483	487	24	0
Sep	8	268	647	--	167	4	60	50	32
Oct	1084	126	--	--	809	1284	25	13	11

Melosira islandica

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	20	--	--	20	54	33	13	17
May	61	25	35	--	24	13	34	25	153
Jun	0	0	0	--	0	0	0	0	0
Jul	0	0	--	--	0	0	0	0	0
Aug	0	0	87	--	0	0	0	0	0
Sep	0	3	0	--	31	0	15	0	0
Oct	3	4	--	--	0	0	0	0	0

TABLE 4 continued.

Melosira italica subsp. *subarctica*

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	29	36	--	--	45	46	22	29	37
May	53	67	35	--	56	52	32	35	197
Jun	0	0	0	--	0	0	0	0	0
Jul	0	3	--	--	0	0	0	0	0
Aug	0	11	211	--	8	0	0	83	0
Sep	31	41	58	--	23	24	3	25	0
Oct	13	95	--	--	3	0	1	4	0

Navicula spp.

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	2	0	0	0
May	3	3	0	--	2	0	0	0	0
Jun	2	0	7	--	2	0	0	0	0
Jul	2	2	--	--	2	0	0	0	0
Aug	7	0	0	--	0	2	2	0	0
Sep	0	23	15	--	10	0	10	5	0
Oct	8	0	--	--	3	7	0	0	0

Nitzschia spp. (all species combined)

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	17	23	--	--	13	24	6	6	12
May	30	3	7	--	24	2	12	10	9
Jun	3	2	53	--	3	0	0	0	0
Jul	13	43	--	--	26	0	0	0	0
Aug	27	33	169	--	20	12	0	11	0
Sep	22	45	156	--	46	30	23	28	7
Oct	73	22	--	--	73	38	33	13	3

TABLE 4 continued.

Oocystis spp.

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	11	0	--	--	7	17	0	3	6
May	0	0	7	--	4	4	0	0	0
Jun	0	0	2	--	3	3	17	3	3
Jul	13	7	--	--	30	10	0	1	1
Aug	2	20	0	--	3	0	2	7	0
Sep	0	0	0	--	0	35	0	18	2
Oct	2	11	--	--	0	2	6	13	0

Oscillatoria spp.

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	2	--	--	17	0	0	0	0
May	22	17	28	--	11	13	11	8	1
Jun	8	5	3	--	3	2	2	7	0
Jul	4	2	--	--	7	0	0	0	0
Aug	0	0	0	--	3	3	2	6	0
Sep	3	3	15	--	0	0	5	5	3
Oct	3	4	--	--	2	0	0	1	1

Rhizosolenia eriensis

		cells/ml							
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	2	0	--	--	0	0	2	0	0
May	0	0	0	--	0	0	0	2	2
Jun	0	7	0	--	0	2	7	7	93
Jul	0	2	--	--	0	0	0	0	0
Aug	0	0	0	--	2	0	0	0	0
Sep	11	10	68	--	10	11	15	17	3
Oct	2	2	--	--	0	0	0	0	2

TABLE 4 continued.

Scenedesmus bicellularis

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	19	19	--	--	14	4	4	0	4
May	0	5	0	--	0	0	12	3	4
Jun	0	0	0	--	0	0	0	0	0
Jul	45	0	--	--	0	0	0	0	0
Aug	5	4	15	--	7	2	7	0	3
Sep	6	3	5	--	2	22	10	0	3
Oct	8	37	0	--	10	7	2	2	2

Scenedesmus quadricauda

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	--	--	0	0	0	0	0
May	0	0	7	--	0	0	0	2	0
Jun	0	0	0	--	2	2	0	0	0
Jul	11	12	--	--	37	0	0	0	0
Aug	2	11	4	--	0	3	0	19	0
Sep	0	0	0	--	0	0	2	0	0
Oct	3	32	--	--	3	5	6	11	0

Scenedesmus spp.

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	0	0	--	--	1	0	0	2	0
May	0	12	0	--	0	0	3	1	0
Jun	2	5	0	--	1	8	0	3	0
Jul	126	24	--	--	117	0	2	0	1
Aug	8	42	3	--	9	25	5	14	0
Sep	0	15	2	--	10	22	4	2	2
Oct	9	75	--	--	8	16	28	9	0

TABLE 4 continued.

Stephanodiscus alpinus

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	15	--	--	15	11	7	2	13
May	33	28	17	--	9	15	12	1	2
Jun	0	0	3	--	0	0	0	0	0
Jul	0	5	--	--	0	0	0	0	0
Aug	0	2	53	--	2	0	7	0	0
Sep	0	10	2	--	8	2	0	3	0
Oct	3	13	--	--	5	0	3	5	6

Stephanodiscus binderanus

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	6	20	--	--	32	41	9	5	4
May	8	17	45	--	71	59	56	14	4
Jun	0	0	0	--	0	0	0	0	0
Jul	11	0	--	--	24	0	0	0	0
Aug	0	0	56	--	5	0	5	0	0
Sep	0	5	2	--	0	0	0	0	0
Oct	0	28	--	--	3	0	0	0	0

Stephanodiscus hantzschii

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	13	--	--	39	33	15	0	19
May	64	0	7	--	13	22	9	1	1
Jun	3	10	3	--	3	7	2	0	0
Jul	0	15	--	--	0	0	0	0	0
Aug	2	0	60	--	5	10	12	4	0
Sep	0	12	44	--	2	7	2	2	2
Oct	45	0	--	--	31	30	5	4	4

TABLE 4 continued.

Stephanodiscus minutus

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	297	280	--	--	553	653	325	110	295
May	481	212	100	--	306	391	105	44	2
Jun	0	7	0	--	0	0	9	0	0
Jul	17	17	--	--	6	0	0	0	1
Aug	2	20	0	--	5	0	12	17	0
Sep	14	2	0	--	0	22	0	15	0
Oct	0	4	--	--	8	0	8	10	0

Stephanodiscus subtilis

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	0	0	0	0	4
May	3	0	0	--	2	9	0	0	0
Jun	18	23	40	--	12	30	6	38	0
Jul	52	19	--	--	65	0	6	0	0
Aug	0	2	0	--	2	0	2	7	0
Sep	0	0	0	--	0	0	0	0	0
Oct	41	13	--	--	73	61	3	2	0

Stephanodiscus tenuis

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	4	6	--	--	11	4	0	1	2
May	8	0	2	--	6	4	0	2	0
Jun	1407	930	985	--	897	1003	833	1468	8
Jul	1183	1061	--	--	1710	3	2	0	1
Aug	45	6	8	--	10	25	18	22	0
Sep	6	2	10	--	2	0	3	0	0
Oct	13	24	--	--	10	12	5	1	0

TABLE 4 continued.

Stephanodiscus spp.

cells/ml									
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	100	91	--	--	135	141	74	39	119
May	314	97	72	--	184	67	34	11	7
Jun	5	5	0	--	0	0	4	0	0
Jul	13	12	--	--	15	0	0	2	0
Aug	17	11	478	--	23	8	23	4	0
Sep	0	48	22	--	23	11	18	15	18
Oct	86	17	--	--	36	53	7	9	9

Synedra delicatissima v. *angustissima*

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	15	--	--	11	13	11	7	3
May	3	6	9	--	24	35	8	11	23
Jun	8	8	8	--	13	3	0	22	16
Jul	4	3	--	--	4	0	0	0	0
Aug	5	17	30	--	0	0	20	2	0
Sep	0	7	15	--	5	4	2	0	15
Oct	0	4	--	--	0	7	0	0	0

Synedra filiformis

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	7	4	--	--	2	6	6	3	6
May	6	3	2	--	9	4	5	6	29
Jun	3	0	25	--	0	7	26	8	35
Jul	4	0	--	--	2	0	0	0	0
Aug	0	7	4	--	3	0	0	2	0
Sep	17	3	129	--	3	24	17	7	2
Oct	13	6	--	--	17	7	10	0	2

TABLE 4 continued.

Synedra ostenfeldii

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	4	--	--	2	0	2	2	2
May	3	0	2	--	2	0	1	1	5
Jun	0	0	12	--	0	7	7	7	25
Jul	0	0	--	--	0	0	0	0	0
Aug	2	0	0	--	0	7	2	0	0
Sep	0	0	22	--	0	0	0	0	0
Oct	0	0	--	--	8	0	0	0	2

Synedra spp.

	cells/ml								
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>
Apr	0	0	--	--	2	7	2	1	1
May	3	6	2	--	184	67	34	7	17
Jun	12	10	0	--	0	2	0	0	51
Jul	0	12	--	--	0	0	0	0	0
Aug	33	0	105	--	2	13	7	0	0
Sep	0	10	61	--	8	0	3	22	12
Oct	0	2	--	--	0	0	0	2	1

Tabellaria fenestrata

	cells/ml								
	NDC-.5-1	SDC-.5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	11	0	--	--	11	58	71	16	26
May	14	6	0	--	33	0	9	7	14
Jun	10	2	3	--	0	0	0	0	0
Jul	0	7	--	--	0	0	0	0	0
Aug	8	35	143	--	3	2	18	4	0
Sep	147	184	723	--	220	271	270	156	35
Oct	38	6	--	--	55	36	3	4	20

TABLE 4 continued.

<i>Tabellaria flocculosa</i>										
cells/ml										
	<u>NDC-.5-1</u>	<u>SDC-.5-1</u>	<u>DC-0</u>	<u>DC-1</u>	<u>DC-2</u>	<u>DC-3</u>	<u>DC-4</u>	<u>DC-5</u>	<u>DC-6</u>	
Apr	0	0	--	--	0	0	0	0	0	0
May	0	0	0	--	0	0	0	1392	0	0
Jun	0	0	0	--	0	0	0	0	0	0
Jul	0	0	--	--	0	0	0	0	0	0
Aug	0	0	0	--	0	0	0	0	0	0
Sep	53	0	73	--	0	13	86	0	0	0
Oct	5	0	--	--	0	0	0	0	0	0

Table 5 presents by station and month the numbers of cells per milliliter, the numbers of forms (species or groups) recognized, and (for what it is worth as a measure of diversity) the numbers of cells per form. The numbers of cells per form have been rounded.

Perhaps the meaningful yield of this table is that it indicates that the low numbers of cells per milliliter, of forms, and of cells per form which were obtained during July, August, and September of 1972 were probably results of unfamiliarity with the Settle-Freeze method and failure to utilize its potential. By October and November 1972 the numbers being obtained were similar to those obtained in 1973.

Table 5 illustrates (yet one more time) the patchiness of the spatial distribution of phytoplankton, both of cells/ml and of numbers of forms. There is a partial trend toward fewer cells/ml and/or fewer forms at stations DC-4, DC-5, and DC-6 away from shore.

Temporal patchiness in all three sets of numbers is evident when the sequence of months is inspected at each station.

TABLE 5. Total numbers of cells/ml, total numbers of forms collected, mean numbers of cells per form, 1973.

		NDC-5-1	SDC-5-1	DC-0	DC-1	DC-2	DC-3	DC-4	DC-5	DC-6
Apr	Total cells/ml	1261	1094			1556	1816	1122	687	1006
	No. forms	47	48			43	53	34	51	53
	Cells/form	26	22			36	34	33	13	19
May	Total cells/ml	1993	1002	1187		1644	1323	784	433	708
	No. forms	54	34	48		52	39	51	54	43
	Cells/form	37	29	24		31	34	15	8	16
Jun	Total cells/ml	1720	1420	1542		1408	1759	1365	2286	1110
	No. forms	36	33	38		32	41	33	37	24
	Cells/form	47	43	40		44	43	41	61	46
Jul	Total cells/ml	3497	4073			4626	466	652	106	696
	No. forms	55	50			62	22	24	16	32
	Cells/form	63	81			74	21	27	6	21
Aug	Total cells/ml	2072	1221	6198		1456	1902	1534	1512	604
	No. forms	40	46	46		47	44	45	48	20
	Cells/form	51	26	134		31	43	34	31	30
Sep	Total cells/ml	974	1650	5374		1332	1269	1322	1162	765
	No. forms	42	57	64		47	43	53	40	40
	Cells/form	23	29	84		28	29	25	29	19
Oct	Total cells/ml	2372	1447			1915	1341	587	692	474
	No. forms	51	63			50	47	57	51	41
	Cells/form	46	23			38	28	10	13	11

From Table 4 the most numerous species or group was selected as being dominant. The summed monthly numbers of cells/ml of the dominant form were divided by the total monthly number of cells/ml from Table 5 to obtain the percentage of the total population which the monthly dominant form comprised. Table 6 gives the results.

TABLE 6. Monthly dominant forms and their abundance in the phytoplankton populations at the Cook Plant in 1973.

Month	Dominant Forms	% of Population
April	<i>Stephanodiscus minutus</i>	29.4
	Flagellates	24.5
May	<i>Stephanodiscus minutus</i>	18.0
June	<i>Stephanodiscus tenuis</i>	59.7
July	<i>Stephanodiscus tenuis</i>	28.0
August	<i>Melosira granulata</i> v. <i>angustissima</i>	32.9
September	<i>Fragilaria crotonensis</i>	22.0
October	<i>Melosira granulata</i> v. <i>angustissima</i>	37.9

Except in the month of June, the dominant forms were not heavily dominant. In June there was a heavy dominance by *Stephanodiscus tenuis*, which comprised 59.7% of the population.

CONCLUSIONS

The Settle-Freeze method of phytoplankton enumeration and identification has been adjudged superior to the Utermöhl settling chamber method, though the latter counts a greater number of forms. The monthly collections in 1973 again exhibited spatial and temporal patchiness of the phytoplankton population. During the monthly surveys 238 phytoplankton forms were collected; of these 50 were abundant. Diatoms were dominants in each month, with flagellates being a co-dominant in April.

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COLIFORM BACTERIA OF THE COOK PLANT AREA, 1973

William L. Yocum

INTRODUCTION

Among other biota which might be adversely influenced by operation of the Cook Plant are bacteria. Total coliform bacteria enumerated by the Field-Hardy Millipore Nutrient Filter method were chosen to be monitored because the method is adapted to the exigencies of field work.

METHODS

Total coliform bacteria samples were collected during May, June, July, August, September, and October 1973 at stations selected from the second stage preoperational biological survey grid (Ayers and Seibel 1973). Samples were collected by Niskin bottle, and bacteria were isolated for culturing and enumeration by a standard Millipore membrane filter technique (Am. Public Health Assoc. 1971; Millipore Corp. 1967).

Bacteria samples were collected concurrently with phytoplankton samples. A self-flushing 5-liter polyvinyl chloride plastic Niskin collecting bottle was lowered on a hydrographic wire to a depth of one meter and tripped shut with a brass messenger. The Niskin bottle was then raised even with the hydrographic platform and detached from the hydrographic wire. The full Niskin bottle was brought on deck and a 250-ml sample drawn into a polyethylene plastic bottle vigorously rinsed with lake water drawn from the Niskin bottle. The sample bottle was capped, labelled, and stored in a refrigerator until the sample could be filtered. The bacteria were isolated and concentrated by

vacuum filtration of 25-, 50-, or 100-ml samples through Millipore Bacteriological Field Monitors. The Millipore Bacteriological Field Monitor consists of a membrane filter backed by an absorbent pad encapsulated in a sterile plastic container which serves as a filter holder and incubation chamber. The filter is 37 mm in diameter and has a pore size of 0.45 mm.

After the bacteria were collected on the filter, 2 ml of M-Endo broth medium was introduced onto the absorbent pad. The Field Monitor was then placed in a Millipore Portable Incubator for incubation at 35°C. Incubation time ranged from 18 to 24 hr, during which individual bacteria multiplied into visible colonies. Upon completion of incubation, the Field Monitors were opened and the filters labelled and dried. The dried filters were then transported to the laboratory for identification and enumeration of the bacteria colonies.

Coliform colonies were identified and counted under low magnification using a binocular dissecting scope containing a light source. The coliform bacteria colonies are identified by a characteristic metallic green sheen.

RESULTS

Stations sampled, sampling frequency, sampling dates and the calculated total coliform density expressed in numbers of cells/100 ml are presented in Table 1. Mean concentrations and standard errors for each station and sampling date are also given in Table 1.

In 1973 the coliform densities generally fell into the range which might be expected to occur in the area of Lake Michigan from which the samples were taken. The average concentrations are relatively low when compared with

TABLE 1. Coliform bacteria found in 1973, bacteria per 100 ml. n = number of samples, S.D. = standard deviation, \bar{x} = mean number of cells per ml.

Station	Date						n	S.D.	\bar{x}
	15 May	20 June	19 July	22 Aug.	20 Sept.	22 Oct.			
DC-2	15	2	8	0	2	6	6	5.50	5.50
DC-3	0	2	2	10	8	22	6	8.16	7.33
DC-4	3	3	0	2	240	4	6	97.01	42.00
DC-5	0	0	0	2	36	0	6	14.56	6.33
DC-6	0	0	0	0	44	0	6	17.96	7.33
NDC-.5-2	51	0	14	2	0	16	6	19.54	13.83
NDC-1-1			14			0	2	9.90	7.00
NDC-1-2			4			12	2	5.66	8.00
NDC-2-1			14						
NDC-2-3			6						
NDC-4-1			26						
NDC-4-3			8						
NDC-4-4									
NDC-7-1			16			4	2	8.49	10.00
NDC-7-3			6				1		6
NDC-7-5		3		4	676	12	4	334.86	173.75
SDC-.5-2	52	0	12	4	0	8	6	19.83	12.67
SDC-1-1			4				1		4
SDC-1-2			6			0	2	3.54	3.50
SDC-2-1			10				1		10
SDC-2-3			8			4	2	2.83	6.00
SDC-4-1			0			0	2		0
SDC-4-3						0	1		0
SDC-4-4			0				1		0
SDC-7-1			6			2	2	2.83	4.00
SDC-7-3						0	1		0
SDC-7-5		1		0	6	0	4	2.87	1.75
n	7	8	22	9	9	18			
S.D.	23.97	1.39	6.60	1.67	224.75	6.55			
\bar{x}	17.29	1.25	7.45	1.56	112.44	5.00			

maximum allowable concentrations for total body contact (Michigan Water Res. Comm. 1968). The relatively high concentrations found during September may reflect influence of sanitary sewage input via the St. Joseph River or one of the smaller tributaries in the area.

The coliform densities were variable and indicate a patchiness of distribution typical of passive planktonic drifters.

CONCLUSIONS

The coliform collections of 1973 were variable and patchy, but generally indicated water of good quality in the Cook Plant region of Lake Michigan. Higher counts at station NDC-7-5 in September may indicate some St. Joseph River plume influence.

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A QUALITATIVE SURVEY OF PERIPHYTIC DIATOMS IN THE VICINITY
OF THE DONALD C. COOK NUCLEAR POWER PLANT

Donald G. Robinson

Abstract. This study of colonizing periphytic diatoms was conducted during the months April through October 1973. Species present indicate mesotrophic to eutrophic conditions throughout the year with little difference in trophic conditions or species present between the stations north and south of the Donald C. Cook Power Plant or between the stations set in 15 and 30 ft of water. Month-to-month species overlap was fairly constant throughout the year at around 50%.

In April large populations of species indicative of high chloride levels were present. This suggests the presence of a longshore thermal bar set up by the warming of the spring water. These species usually have their origins in rivers, in this case most likely the St. Joseph River, ten miles north of the plant.

Comparison of the data for 1972 and 1973 shows considerable seasonality for the species present. However, many of the major species, though showing the same seasonal trends, exhibit a fair degree of differences in abundance from year to year.

INTRODUCTION

This report continues the qualitative periphyton monitoring program begun two years ago by Great Lakes Research Division for the Donald C. Cook Power Plant. Diatoms were considered exclusively for all months except July when all forms of microscopic "aufwuchs" were considered.

Four periphyton collectors, each holding duplicate styrofoam blocks at a depth of one foot, were emplaced in March. Periphyton was collected monthly at 15- and 30-ft depth stations (approximately one-quarter and one-half mile from shore respectively) at the north and south boundaries of the Cook Plant (about 6,000 ft apart) for the months April through July, the two south stations in August, and three stations in September and October (station N 15 was lost in a late July storm).

METHODS AND MATERIALS

All periphyton blocks collected were frozen and transported to Ann Arbor where the "aufwuchs" were removed and cleaned for identification of diatoms by A. van der Werff's (1955) hydrogen peroxide-potassium dichromate method. When the reaction is over the blocks are removed from the beakers, rinsed with distilled water, and the diatoms allowed to settle. The diatoms are then rinsed with successive changes of distilled water until the solution is clear. The diatoms are then settled overnight and as much supernatant removed as provides for a suitable dilution. The diatoms are next put in suspension and eye-dropped on a 22 mm² cover slip and evaporated at 200°F until all water is gone. The cover slips are then baked at 450°F for ten minutes. The slips are then mounted with Hyrax on microscope slides and put on a hot plate to evaporate the toluene from the mounting medium. Identification of diatoms (see Table 1) was done with an oil immersion Leitz Ortholux at approximately 1250X. All specimens were identified to species, variety, and form when possible. Taxonomic references are cited following the report's "References Cited" section.

TABLE 1. 1972-73 Master species list by species and station. D = Dominant; p = Predominant; 0 = Occurred; R = Rare.

[illegible]

TABLE 1 continued.

Species	1972						1973											
	May	Jun	Jul	Aug	Oct		May	Jun	Jul	Aug	Sep	Oct						
	Stations N15 N30 N40 N15 N15	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30	S15 S30 N15 N30
<i>A. michiganensis</i>																		
<i>A. montana</i>																		
<i>A. neglecta</i>																		
<i>A. neglecta</i>																		
<i>A. ovalis</i>																		
<i>A. ovalis v. constricta</i>																		
<i>A. ovalis v. gracilis</i>																		
<i>A. ovalis v. libyca</i>																		
<i>A. ovalis v. petiolatus</i>																		
<i>A. ovalis v. p.</i>																		
<i>A. rotunda</i>																		
<i>A. sibirica</i>																		
<i>A. subcostulata</i>																		
<i>A. venusta</i>																		
<i>A. venusta v. angularis</i>																		
<i>A. v. (our #13)</i>																		
<i>A. sp.</i>																		
<i>Anomoeoneis vitrea</i>																		
<i>Asterionella bleekeri</i>																		
<i>A. formosa</i>																		
<i>Bacillaria</i> sp.																		
<i>Calanoida alpestris</i>																		
<i>C. calanoides v. blavensis</i>																		
<i>C. boettlingi</i>																		
<i>C. boettlingi v. lanostula</i>																		
<i>C. clevei</i>																		
<i>C. liber</i>																		
<i>C. schwanzen</i>																		
<i>C. schwanzen</i>																		
<i>C. ventricosa v. minuta</i>																		
<i>C. ventricosa v. truncatula</i>																		
<i>C. ventricosa (v. our #2)</i>																		
<i>Coconotus diminuta</i>																		
<i>C. discus</i>																		

TABLE 1 continued.

Species	1972												1973												
	May	Jun	Jul	Aug	Oct	Apr	May	Jun	Jul	Aug	Sep	Oct	May	Jun	Jul	Aug	Sep	Oct							
Station	N15	N10	N30	N15	N15	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30
<i>C. plectinula</i>																									
<i>C. placentula</i>																									
<i>C. placentula v. euclippia</i>																									
<i>C. placentula v. lineata</i>																									
<i>C. sp. (our #1)</i>																									
<i>Concinchianus subaequalis</i>																									
<i>Cyclotella atomus</i>																									
<i>C. comta</i>																									
<i>C. auxospore</i>																									
<i>C. cryptica</i>																									
<i>C. Kitzingiana</i>																									
<i>C. Kitzingiana v. planatophora</i>																									
<i>C. Kitzingiana v. rotifera</i>																									
<i>C. Kitzingiana auxospore</i>																									
<i>C. Kitzingiana</i>																									
<i>C. mureghiana</i>																									
<i>C. mureghiana v. plana</i>																									
<i>C. mureghiana</i>																									
<i>C. coelata</i>																									
<i>C. operculata</i>																									
<i>C. pseudostelligera</i>																									
<i>C. stelligera</i>																									
<i>C. amplicapitata</i>																									
<i>C. sp. (our #1)</i>																									
<i>Cymatopleura colchica</i>																									
<i>C. solca</i>																									
<i>C. solca v. apiculata</i>																									
<i>Ophidilla affinis</i>																									
<i>C. amphicapitata</i>																									
<i>C. atenuata</i>																									
<i>C. campidata</i>																									
<i>C. campidata v. ?</i>																									
<i>C. detrita</i>																									
<i>C. detrita v. ?</i>																									
<i>C. lanceolata</i>																									
<i>C. latens</i>																									

TABLE 1 continued.

Species	1972												1973															
	May			Jun			Jul			Aug			Sep			Oct												
	Station	N15	N30	N15	N30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15
<i>C. leptoceros</i>																												
<i>C. macrodon</i>																												
<i>C. microcephala</i>																												
<i>C. nana</i>																												
<i>C. nana</i> f. <i>formosa</i>																												
<i>C. obtusicauda</i>																												
<i>C. parvula</i>																												
<i>C. prostrata</i> v. <i>caespitosa</i>																												
<i>C. puposa</i>																												
<i>C. sinuata</i>																												
<i>C. sinuata</i> f. <i>ovata</i>																												
<i>C. subventricosa</i>																												
<i>C. tumida</i>																												
<i>C. tumida</i>																												
<i>C. turgida</i>																												
<i>C. ventricosa</i>																												
<i>C. sp. (our #13)</i>																												
<i>C. sp.</i>																												
<i>Denticula tenuis</i>																												
<i>Datana ehrenbergii</i>																												
<i>D. hians</i>																												
<i>D. hians</i> v. <i>mesodon</i>																												
<i>D. tenuis</i>																												
<i>D. tenuis</i> v. <i>elongata</i>																												
<i>D. tenuis</i> v. <i>longicauda</i>																												
<i>D. vulgare</i>																												
<i>D. vulgare</i> v. <i>breve</i>																												
<i>D. vulgare</i> v. <i>grande</i>																												
<i>Ditachyon diversus</i>																												
<i>Diplosia oculata</i>																												
<i>D. parva</i>																												
<i>D. subnatis</i>																												
<i>D. sp.</i>																												
<i>Epithemia arvens</i>																												

[illegible]

TABLE 1 continued.

Species	1972												1973												
	May				Jun				Jul				Aug				Sep				Oct				
	Station	N15	N30	N30	N15	N30	N15	N30	S15	S30	N15	N30	S15	S30	N15	N30	S15	S30	N30	S15	S30	N30	S15	S30	N30
<i>G. sublanatum</i>																									
<i>G. tergestinum</i>																									
<i>G. sp. (our #3)</i>																									
<i>G. sp. (our #13)</i>																									
<i>G. sp. (lits no description)</i>																									
<i>Ophrosigma acuminatum</i>																									
<i>G. attenuatum</i>																									
<i>G. apenninensis</i>																									
<i>G. apenninensis v. aurula</i>																									
<i>G. sp.</i>																									
<i>Hemitaphia amphioxys</i>																									
<i>Mastoglossa grevillei</i>																									
<i>M. smithi v. amphioxys</i>																									
<i>M. smithi v. lacustris</i>																									
<i>Melospiza amphioxys</i>																									
<i>M. distans v. albigena</i>																									
<i>M. granulata</i>																									
<i>M. granulata fo. spiralis</i>																									
<i>M. granulata v. angustissima</i>																									
<i>M. italica</i>																									
<i>M. varians</i>																									
<i>Meridion ciliolare</i>																									
<i>M. ciliolare v. constrictum</i>																									
<i>Nasella coarctata</i>																									
<i>N. amphioxys</i>																									
<i>N. anglica</i>																									
<i>N. anglica v. signata</i>																									
<i>N. anglica v. subulata</i>																									
<i>N. cauroa</i>																									
<i>N. ciliolare</i>																									
<i>N. bolsonia</i>																									
<i>N. capitata</i>																									

[illegible]

TABLE 1 continued.

Species	1972												1973											
	May				Jun				Jul				Aug				Sep				Oct			
	Station	N15	N30	N45	Station	N15	N30	N45	Station	N15	N30	N45	Station	N15	N30	N45	Station	N15	N30	N45	Station	N15	N30	N45
<i>N. tamsila v. minor</i>																								
<i>N. tamsila v. obtusae</i>																								
<i>N. tamsila fo. rostrata</i>																								
<i>N. tamsila (our v. #1)</i>																								
<i>N. viridula v. attenuata</i>																								
<i>N. viridula v. linearia</i>																								
<i>N. viridula v. fenella</i>																								
<i>N. valpinea</i>																								
<i>N. sp. (our #13)</i>																								
<i>N. sp. (our #29)</i>																								
<i>N. sp. (our #35)</i>																								
<i>N. sp. (our #39)</i>																								
<i>N. sp. (our #40)</i>																								
<i>N. sp. (our #55)</i>																								
<i>N. sp. (our #78)</i>																								
<i>N. sp. (our #79)</i>																								
<i>N. sp. (our #80) (Pueria)</i>																								
<i>N. sp. (aff. n. oppugnata)</i>																								
<i>N. sp.</i>																								
<i>Medusa distincte-punctatum</i>																								
<i>N. dubium v. conspurcatorum</i>																								
<i>N. dubium v. #1</i>																								
<i>N. sp. (our #3)</i>																								
<i>N. sp. (our #4)</i>																								
<i>N. sp.</i>																								
<i>Hizukia acuminatoides</i>																								
<i>N. acuminata</i>																								
<i>N. acuta</i>																								
<i>N. amphibia</i>																								
<i>N. amphibia v. foetida</i>																								
<i>N. angustata v. acuta</i>																								
<i>N. angustata</i>																								
<i>N. boreata</i>																								

[illegible]

[illegible]

RESULTS

All identified specimens are arranged by station and date in Table 1. In addition, the 1972 results are listed for a year-by-year comparison. The specimens are coded by "R" for rare (occurring only one or two times on half a cover slip), "O" for occurred, "P" for predominant (i.e., of marked importance in the community but not exerting control), and "D" for dominant. In August and October 1972, there are listed two "D's" for each month since the dominants were equally represented. The ecological significance of the predominant and dominant species are listed in Table 2.

TABLE 2. Ecological significance of predominant and dominant species. (Superscripts refer to references cited at the end of the table, p. 199.)

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-
1. *Achnanthes minutissima* and *A. minutissima* v. *cryptocephala* - Eurytopic^{2,10} eurythermal, euryzonal, oligohalobe, probably indifferent²; pH optimum 7.5-7.8⁴ but found in large numbers from 6.5-9.0¹⁰; excellent indicator of oxygen rich conditions in weakly to moderately alkaline waters⁴; listed seventeenth in the top twenty species of diatoms tolerating organic pollution⁹; the varietal name has been dropped by some taxonomists, but for identification purposes a more conservative approach was favored¹⁰.
 2. *Cyclotella stelligera* - Thrives in eutrophic waters; pH optimum at or above 8.5⁴.
 3. *Cymbella microcephala* - Cannot withstand great pH changes so it is a good indicator of slightly alkaline oligotrophic conditions; pH optimum at or above 7.0; saturated oxygen conditions optimal for growth⁴. Oligohalobe to indifferent; littoral².
 4. *Cymbella prostrata* - Oxygen rich conditions optimal for growth; pH optimum over 8.0; can live through a slight osmotic pressure change⁴. Occasional in brackish but commonly in fresh water^{3,5}.
 5. *Diatoma tenue* - Often found in relatively highly conductive or slightly salty water¹⁰; pH optimum 7.4-7.8; cannot withstand osmotic pressure changes⁴.

TABLE 2 continued.

6. *Diatoma tenue* v. *elongatum* - In Lake Michigan usually in greatest numbers in areas heavily eutrophied¹¹; cannot withstand osmotic pressure changes; pH optimum 7.4-7.8⁴; oligohalobous according to Bourelly², but reported in brackish waters by Patrick and Reimer¹⁰.
7. *Diatoma vulgare* - The only species of the genus that can stand eutrophic water but is not a nitrogen heterotroph⁴; often found in water with high nutrient content¹⁰; littoral; indifferent²; listed as twelfth in the top twenty diatom species tolerating organic pollution³; prefers alkaline water; beta-mesosaprobic to oligosaprobic.
8. *Fragilaria construens* v. *capitata* - The nominate variety finds its greatest abundance in Lake Michigan in appreciably eutrophied inshore areas¹¹. Prefers slightly alkaline water; indifferent to chlorides¹⁰. Our specimens of the variety *capitata* showed considerable intergradation with the variety *binodis* (described as tolerating high conductivity)¹⁰.
9. *Fragilaria intermedia* - One of the most characteristic species of lightly alkaline oxygen rich waters; pH optimum over 7.0 but rarely over 8.4⁴.
10. *Fragilaria vaucheriae* v. *truncata* - Primarily periphytic¹¹.
11. *Gomphonema angustatum* v. *producta* - Cosmopolitan; littoral; oligohalobe².
12. *Gomphonema olivaceum* - Does not live in brackish water; pH optimum 8.0-8.5⁴; tolerates beta-mesoprobic conditions at most according to McFarland⁸ and when found in streams it is associated with pollution¹.
13. *Gomphonema subclavatum* - Fresh water⁵; primarily periphytic.
14. *Melosira granulata* - In Lake Michigan greatest occurrence in eutrophic areas¹¹; cosmopolitan; euplanktonic; pH optimum 7.9-8.2⁴; listed eleventh in the top twenty species of diatoms tolerating organic pollution³; most characteristic diatom of eutrophic waters; typically absent under oligotrophic conditions⁶.
15. *Melosira italica* - Cosmopolitan; littoral planktonic form of eutrophied waters²; pH optimum not under 8.0⁴.
16. *Navicula radiosa* v. *tenella* - Circumneutral waters; oligohalobous to indifferent salt concentrations¹⁰; fresh water⁵.
17. *Navicula tripunctata* - Fresh to slightly brackish water¹⁰.
18. *Navicula viridula* - Prefers slightly alkaline fresh water¹⁰; pH optimum

TABLE 2 continued.

- 7.5⁴; littoral; cosmopolitan; oligohalobe²; listed thirteenth in the top twenty diatoms tolerating organic pollution⁹; fresh to slightly brackish water⁵.
19. *Navicula viridula* v. *avenacea* - Similar to nominate variety.
20. *Nitzschia confinis* - Prefers eutrophic waters; pH optimum 7.5-8.0⁴.
21. *Nitzschia dissipata* - Fresh to brackish water^{3,12}; pH optimum around 8.0 perhaps a bit under; withstands pH and osmotic changes poorly⁴.
22. *Nitzschia fonticola* - Can withstand large osmotic fluctuation; pH optimum 8.2-8.6; obligate heterotrophic species, requires amino acids⁴.
23. *Nitzschia Kdtzingiana* - Obligate heterotrophic species, requires amino acids; pH optimum 7.5-7.8⁴; oligohalobe and littoral form².
24. *Nitzschia palea* - Indifferent oligohalobe²; one of the most abundant species of strongly eutrophic oxygen rich alkaline water; pH optimum over 8.0⁴; pH range 4.3-8.5 but prefers alkaline environment²; a very good indicator of pollution as it is very eurytopic but without organic nitrogen it cannot greatly increase its numbers; obligate nitrogen heterotroph, deaminates amino acids quickly so self-purification is very great⁴; cosmopolitan²; fresh water^{3,12}; listed first in the top twenty diatoms tolerating organic pollution⁹; alpha-mesosaprobic; euryhaline; eurythermic¹.
25. *Stephanodiscus alpinus* - Often reported as *S. astraea* of *S. astraea* v. *minutula*; very common in hypolimnion of alpine lakes¹¹.
26. *Stephanodiscus hantzschii* - In the plankton of Lake Michigan it only occurs in great quantities in eutrophied inshore portions¹¹; probably obligate nitrogen heterotroph; withstands pH changes poorly; pH optimum around or over 8.2⁴; listed ninth in the top twenty diatoms tolerating organic pollution⁹.
27. *Stephanodiscus minutus* - Often reported as *S. astraea* v. *minutula*; only becomes abundant in Lake Michigan in eutrophied inshore areas and estuaries¹¹.
28. *Stephanodiscus subtilis* - In Lake Michigan only abundant in eutrophied areas receiving considerable chlorides; probably only thrives in these conditions¹¹.
29. *Stephanodiscus tenuis* - Often confused with *S. hantzschii*. Not observed in southern Lake Michigan until mid 1950's; pollution tolerant¹³.

TABLE 2 continued.

30. *Synedra acus* - Cosmopolitan; prefers water that is circumneutral and without a low conductivity; found in water of medium hardness most often¹⁰; pH optimum 7.4-7.6⁴; littoral; oligohalobe; indifferent²; listed fourteenth in the top twenty diatom species tolerating organic pollution⁹.
31. *Synedra fasciculata* - In waters with high conductivity to slightly brackish¹⁰; in Lake Michigan in polluted harbors and in areas of high chloride contamination¹¹.
32. *Synedra filiformis* (v. *exilis*?) - Prefers water low in minerals¹⁰.
33. *Synedra minuscula* - Circumneutral⁴; prefers cool water¹⁰.
34. *Synedra pulchella* - Brackish water diatom with high permeability for chlorides and carbonates; in such conditions can be very abundant⁴; in fresh water associated with high mineral content¹⁰. "It is very rare in Lake Michigan at the present time, but can be expected to become more abundant in areas receiving heavy pollution wastes high in chloride"¹¹.
35. *Synedra radians* - Prefers slightly alkaline water with relatively high conductivity¹⁰.
36. *Synedra rumpens* - Widely distributed in fresh water¹⁰; pH optimum 6.4-6.8⁴.
37. *Synedra tenera* - Prefers water of low conductivity¹⁰; pH optimum under neutral point; according to Cholnoky is abundant only in so called tropical to subtropical waters and surely not in northern alpine waters⁴.
38. *Synedra ulna* - Listed second in the top twenty species of diatoms tolerating organic pollution⁹; littoral form; indifferent; euryhaline; found in eutrophic lakes, stagnant water, swamps, bogs, and pools²; pH optimum around 7.8⁴.
39. *Synedra vaucheriae* and *S. vaucheriae* v. *capitellata* - Considered together here as there was considerable intergradation, although in no case did the variety outnumber the nominate. Wet-mount examinations showed occurrence singly and in colonies so the genus name *Fragilaria* would seem to be equally suitable. The nominate variety was a persistent predominant throughout the year indicating eurytopicity. The varietal form is considered by Bourelly as a littoral form of stagnant waters².
40. *Synedra* sp. (affin *S. amphicephala* v. *austriaca*) -
41. *Tabellaria fenestrata* - Prefers mesotrophic to fairly eutrophic waters that are circumneutral^{7,10}; pH optimum 5.8 but found in waters with much higher pH⁴.

TABLE 2 continued.

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42. *Thalassiosira pseudonana* - This genus is found primarily in marine and brackish water. Its occurrence in Lake Michigan indicates high chloride pollution where it is found in significant quantities¹¹.
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DISCUSSION

Gomphonoma olivaceum, the dominant species in April and May, overlapped into June as a predominant. In June and July *Diatoma tenue* was the dominant with predominant overlaps into the two preceding months, April and May, and into the following month, August. In August there were two dominant species, *Achnanthes minutissima* and *Synedra radians*. *Achnanthes minutissima* had just an occurring overlap in July, but continued as the dominant in September and one of two dominants in October. The identification of *Synedra radians* was a difficult choice as the species has a variable shape and central area, and the specimens observed on the August slides were uniformly in the lower limits of the species's size range. The lack of this species overlapping at all into adjacent months may be a reflection of this difficulty. October's slides were dominated by *Synedra vaucheriae*, which was also a predominant in every preceding month, and by *Achnanthes minutissima*. *Nitzschia dissipata* never reached dominant status but was a predominant from April through September. Other species found occurring in sizeable amounts throughout the year were *Tabellaria fenestrata* and *Synedra filiformis*. All of the above-named species in this section rated at least an "0" for occurred status every month sampled except for *Gomphonema olivaceum*, which was listed as rare in August.

Of particular interest is the occurrence of the predominant species *Stephanodiscus subtilis*, *Synedra fasciculata*, *Synedra pulchella*, and *Thalassiosira pseudonana* in April, and to a lesser extent in the following two months of

this survey. All of these species are excellent indicators of high chloride contamination. These species are perhaps of a riverine origin, probably the St. Joseph River since no significant outfalls have been detected in this area. This indicates the presence of a longshore thermal bar set up in part of April by the warming of the springtime waters (Stoermer 1968).

Significantly fewer kinds of species were found in the first two months, especially April. There was also considerably less species overlap in a given month on a station-to-station basis. These findings are congruent with the lower biomass and are to be expected due to colder water and less sunlight inhibiting the growth rates (Patrick et al. 1968).

Indicator species showed no difference in trophic levels between 15-ft and 30-ft sets but perhaps some between the north and south stations. Predominant or dominant eutrophic species numbered 22 at the north stations and 18 at the south stations, and 20 at both the 15- and 30-ft sets. If the missing N 15 and N 30 stations in August and the N 15 station in September and October could have been included, there might have been an even larger difference between the north and south stations. This difference may be a result of the St. Joseph River's influence.

There was no significant difference in the number of species found at 15- and 30-ft sets or north and south stations. In the months of April through July when all stations were present, there was a rounded average of 106 forms found at each south station and 105 at each north station. The averages for the 15- and 30-ft sets were 115 and 111 respectively. At each station throughout the sampling season the average was 124. The average month to month species overlap was 52% (see Table 3).

Comparison of 1972 and 1973 data establishes a definite seasonality of the

species, almost all of which seem to be monacmic, i.e., one bloom peak per year. However, it was found that one could not necessarily expect to find these species in the same abundance from year to year.

TABLE 3. Month to month species overlap, 1973.

Month	Total species found for both months	Overlapping species	Percent overlap
April-May	203	103	51%
May-June	269	139	52%
June-July	342	162	47%
July-August	299	150	50%
August-Sept.	258	139	54%
Sept.-Oct.	265	150	57%
Round average	273	141	52%

The species present throughout the 1973 sampling season show fairly eutrophic water. Of the top 13 diatom genera tolerating organic pollution, 11 were represented in this survey as either dominants or predominants. For the top 17 species, 8 were present as dominants or predominants (Palmer 1971). Although the appearance of a particular species as a dominant or predominant does not necessarily type the water, the overwhelming abundance of eutrophic indicator vs. oligotrophic indicator species definitely shows a high productivity for the area studied.

SUPPLEMENTARY PERIPHYTON/PSAMMON COLLECTION, 17 July 1973

The sampling was prompted by desire to investigate possible psammon diatom

concentrations offshore and by belief that periphyton blocks measure phytoplankton colonization rates rather than represent true periphyton communities which are usually benthic in nature.

The 13-ft Boston Whaler was anchored on the first sand bar, approximately 75 ft from shore at the north range pole. Seastate was nearly flat but on the previous day was 1-2 ft waves.

Collection was done by two skin divers using mask, fins, snorkel (Seibel, Williams). One man remained in the Whaler to log comments made by the sampling team. The sampling team carried capped deflated 8-oz polybottles. To sample, the bottle was uncapped and material was sucked into the bottle.

The first examination transect was towards shore from the boat along the bottom in a few feet of water. Ripple marks were distinct, 4-6 inches apart, one inch high, all asymmetrical, with high concentrations of heavy minerals in their troughs. No diatom concentrations were seen. A large lump of concrete and a bough submerged in 2 ft of water near shore yielded algae (Bottle A).

The second transect ran offshore in 5-6 ft of water, 50 ft away from the boat. In the troughs of the ripple marks was conglomerated, gelatinous material with a faint green tint. The material was slightly positively buoyant. Two bottles were collected, B and C.

There was a higher concentration of the material 75 ft offshore from the boat. Two samples, D and E, were taken.

The final series was collected near the second sandbar in 6-10 ft of water. The ripple marks were larger here than inshore. The material was longer here from 2-4 inches and 1.5 inches as a maximum width. It held together better when sampled than what was collected previously. Two samples, F and G, were taken.

The samples were immediately taken to the fish trailer and preserved with

6:3:1 algal preservative.

In Ann Arbor the samples were examined with a Leitz Ortholux scope at magnifications of 125X, 250X, and 540X (oil immersion) using wet mounts.

The first impression of the material was that it was "flocculent, organic detritus" with the green tint coming possibly from live algae. Microscopic examination showed it to be predominately live algae with some inorganic material in the matrix, some copepods and rotifers. One *Aeolosoma* was found.

Algae identified

Sample A - from submerged concrete bough:

Cladophora sp.
Stigeoclonium sp.

Sample B and C:

Bulbochaetae sp.
Mougeotia sp.
Pediastrum sp.
Scenedesmus sp.
Ulothrix sp.

Sample D:

Bulbochaetae sp.
Chaetophora sp.
Cladophora sp. (not predominant)
Closterium sp.
Gymnodinium sp.
Merismopedia sp.
Pediastrum holopedium
Scenedesmus quadricauda
Scenedesmus sp.
Ulothrix zonata ?
green filament - *Ulothrix* or *Mougeotia*
diatoms - *Diatoma* sp., *Fragilaria* sp., *Cymbella* sp. (growing on the filaments), *Gomphonema* sp. (growing on the filaments), *Melosira* sp., *Tabellaria fenestrata*

Sample E:

Bulbochaetae sp.
Mougeotia sp.

Spirogyra sp.
Ulothrix sp.
Scenedesmus quadricauda v. *Westii*
Scenedesmus quadricauda
same diatoms as Sample D (also *Melosira varians*)

Sample F and G:

Bulbochaetae sp.
Gomphosphaeria sp.
Gymnodinium sp.
Merismopedia sp.
Pediastrum sp.
Scenedesmus crassus
Scenedesmus quadricauda
Spyrogyra sp.
Ulothrix sp.
same diatoms as Sample D

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PSAMMON AS FOOD FOR LAKE MICHIGAN SHOREBIRDS

John C. Ayers

Abstract. Stomach analyses of 22 Lake Michigan shorebirds, semipalmated plovers, semipalmated sandpipers, and sanderlings revealed no evidence of psammon being used as food. Insects were the main food, with beetles being most common.

INTRODUCTION

In the recent past there have been repeated statements that members of the psammolittoral community constitute important food items for shorebirds, and that heat or chlorine in power plant discharge plumes would or could destroy this community and produce adverse environmental impact by depriving shorebirds of essential food.

To get an evaluation of this statement we approached the Bird Division of the University of Michigan Museum of Zoology and were put in touch with Joseph G. Strauch, Jr., a Ph.D. candidate working on the food habits of shorebirds in their wintering grounds. He was pleased with the chance to investigate these birds as they passed Lake Michigan on their fall migration south.

We provided transportation, support, and assistance for a collecting trip on 30 and 31 August 1973 to the Cook Plant and adjacent beaches.

METHODS

Collections were made by shotguns, both by shooting from the beach and from a boat. Stomachs were immediately removed from the birds and preserved

in formalin for microscopic examination in the laboratory.

RESULTS

Mr. Strauch's report is given here in its entirety.

Food Habits of Shorebirds Near the Cook Power Plant, Berrien County, Michigan. Joseph G. Strauch, Jr., Bird Division, Museum of Zoology, University of Michigan.

On August 30 and 31, 1973, I collected 22 shorebirds of three species; Semipalmated Plover (*Charadrius semipalmatus*), Semipalmated Sandpiper (*Calidris pusillus*), and Sanderling (*Calidris alba*), on Livingston Beach adjoining the Cook Power Plant (three of the Sanderlings were actually collected about 1.5 miles north of the plant). The birds were feeding on the beach, either along the water's edge, or along two small ponds and a stream on the beach. In a census of the birds taken late in the afternoon of 30 August I found two Semipalmated Plovers, two Killdeer (*Charadrius vociferus*), about ten Semipalmated Sandpipers, and about twenty Sanderlings. A census of the birds along the shore taken from a boat on 31 August turned up 31 Sanderlings between the power plant and Warren Dunes State Park to the south, and six Sanderlings and five Spotted Sandpipers (*Actitis macularia*) between the power plant and Grand Mere to the north. A total of 42 birds was found along ten miles of beach; there were probably more than 200 people along this same stretch of beach.

Table 1 gives the results of an analysis of the stomach contents of the birds collected. Insects were the main prey for all the birds, with beetles accounting for perhaps 60% of the prey individuals taken. Most of the beetles taken belong to the family Curculionidae. The Semipalmated Plover ate only terrestrial prey, while the two species of Sandpiper ate both aquatic and terrestrial prey.

An individual Bonaparte's Gull (*Larus philadelphia*) collected on 31 August had insects (Orthoptera, Homoptera, Coleoptera, and Formicidae) and fish bones in its stomach.

TABLE 1. Frequency of occurrence of prey in the stomachs of three species of shorebirds collected on Lake Michigan near the Cook Power Plant, Berrien County, Michigan.

Food Items	Species of Shorebird		
	<i>Charadrius semipalmatus</i> (N = 4)	<i>Calidris pusillus</i> (N = 6)	<i>Calidris alba</i> (N = 12)
Gastropoda (snails)	0	16	0
Crustacea	0	33 ¹	8
Insecta			
Orthoptera (grasshoppers and roaches)	0	0	8
Hemiptera (true bugs)	0	16	25
Coleoptera (beetles)	100	100	100
Diptera (flies)	0	33	17
Hymenoptera (wasps, bees) (other than ants)	0	33	17
Formicidae (ants)	75	67	83
Homoptera (leaf hoppers)	0	0	25
Insect larvae ²	75	16	17
Fish (at least part carrion)	0	0	25
Plant material	50	33 ³	0

¹Amphipoda only.

²All orders, at least Coleoptera and Diptera present.

³Seeds only.

SUMMARY AND CONCLUSIONS

Microscopic examination of stomach contents of shorebirds collected while they were feeding on the beaches near the Cook Plant showed no evidence that psammon were being utilized as food by the shorebirds.

This was not unexpected. Seibel et al. (1973) say (p. 12): "The largest organism present was an elongate, cylindrical microturbellarian, designated species 1 for this report, which reached a length of 4 mm. At this size it is visible to the unaided eye only as a minute white thread."

REFERENCE

- Seibel, E., J. C. Roth, J. A. Stewart and S. L. Williams. 1973. Benton Harbor Power Plant limnological studies. Part XVI. Psammolittoral investigation 1972. Univ. Michigan, Great Lakes Res. Div. Spec. Rep. 44.

LAKE MICHIGAN ZOOPLANKTON COMMUNITIES IN THE AREA
OF THE COOK NUCLEAR PLANT

John A. Stewart

Abstract. Methods tentatively planned for a study of entrained zooplankton are described and discussed. Preliminary trials suggest the methods provide an efficient means of sampling. Results of seven monthly field surveys taken in 1973 are introduced and compared with results from past years. Composition and seasonal succession followed previously observed patterns, but absolute abundances often differed by factors of two or more. Higher abundances in the spring were followed by lower midsummer peaks. Chief differences between night samples and those collected in the daytime were the addition of *Mysis* to offshore plankton and the addition of *Eurycerus* inshore. A study of vertical distribution found highest zooplankton concentrations at middle depths. Natural histories of each of the Cook area species are compiled and used to construct a synopsis of the yearly zooplankton cycle.

INTRODUCTION

A serious disturbance in any one sector of a complex ecosystem can be expected to be propagated to other sectors. Because of their central position in aquatic food chains, zooplankton would be likely intermediaries in sequences of events leading to alterations of economic or aesthetic importance. The Cook study is designed to detect both temporal and spacial aberrations in the planktonic community contained within an approximately 98 square mile area surrounding the plant. Since these waters circulate and are ultimately mixed with the main

body of Lake Michigan, monitoring efforts necessarily focus on potential disturbances that are most immediate in their impact. This report presents the results of work done in 1973 toward the establishment of a pre-operational knowledge of the zooplankton crustacea.

ENTRAINMENT STUDY METHODS

In 1974, studies will be undertaken to determine the kinds and numbers of planktonic organisms entrained in the cooling water and to measure their ability to survive the physical, thermal and pressure stresses associated with condenser passage. Methods we propose to use for a study of zooplankton are presented in this section, with the results of a limited series of trials we were able to carry out during the first part of 1973.

Sample water will be taken from both the intake forebay and discharge bay by identical 1.5 horsepower diaphragm pumps capable of withdrawing about 80 gal/min through a 3-inch diameter pipe. This type of pump cannot be made isokinetic, since pressure waxes and wanes during each pumping stroke. Its advantage is that the absence of a propeller blade permits the passage of larger organisms through the system. The water will be filtered through a #10 mesh plankton net suspended in a barrel of water. This system was chosen in hopes of minimizing physical damage to the sampled animals. If a valve at the base of the barrel is adjusted until a constant water level is maintained, flow through the outlet will be the same as the pumping rate. Thus a flowmeter at this location can measure the volume of filtrate without impinging zooplankton on its blades. In all trials of the system, the sampling pumps operated at a constant 56 cycles per minute; but the volume drawn by this many strokes varied from 60 to 77 gallons, depending on head and on flow characteristics at the sampling position.

Despite certain disadvantages, it is our belief that direct observation of live animals is the most reliable and reproducible means of assessing damage. In addition to providing information about mortality, it permits the detection of behavioral changes such as the assumption of a torpid state reported by Coker (1934) and by Industrial Biotest (1973). Our method will be similar to that used by us for handling preserved samples, employing a separate formalin-free set of equipment. Subsampling will be carried out with a Folsom plankton splitter. This device presents a large surface on which animals can become stranded and thus injured. Therefore it will be best to keep sample sizes small in order to minimize the number of times they must be split. Small samples also limit the effects of crowding during incubation. We have found that if live samples are split only a few times and if each splitting is followed by a rinse with an equal volume of filtered lake water, increases in mortality are not detectable. Pipettes are a less satisfactory means of subsampling, for live copepods can be observed to orient themselves away from the nozzle and escape. In addition, cladocerans trapped on the surface are not subsampled by a pipette.

The subsample will be concentrated into a chamber consisting of a circular groove with a glass bottom. Immobile organisms settle to the bottom of the chamber where they can be identified and counted under a dissecting microscope in the field laboratory, motile zooplankters being ignored. The entire sample will then be preserved and sent to Ann Arbor for counting.

This method does not permit mortality measurements on a large number of samples collected within a single day, and questions whose answers required much intensive sampling would have to be approached in another way. However, it is adequate to accumulate, over a one-year span, the following information: (1)

The total number of each major species passing through the condensers in each month. These estimates would have to account for diurnal cycles and temporal variation. They are best obtained by means of large samples collected in the well-mixed discharge bay and immediately preserved. (2) Mortality rates for each major species in each month. These estimates are best obtained by examining for motility small samples collected in pairs at the discharge bay and at a control area in the intake forebay.

A satisfactory vital staining technique would reduce the time to be spent in the field. To that end, Mohammed Omair, of our staff, has carried out a study of the usefulness of some common bacteriological stains for separating zooplankton crustacea. All stains were added from stock solutions to water containing live and dead zooplankters, producing the indicated final concentrations. After one half hour, the animals were filtered onto netting, washed, and then preserved in a formalin solution.

	<u>Final conc.</u>	<u>Live/dead specificity</u>	<u>Easily distinguished</u>
Eosin Y	1:2000	no	yes
Erythrosin B	1:2000	yes	yes
Neutral red (acidified)	1:20,000	yes	no
Nigrosin	1:2000	no	no
Trypan blue	1:2000	no	no

The most promising dye, Erythrosin B, was subjected to a more complete examination. The stain acts on dead tissue imparting a bright rose color whose retention is excellent. But it will at times color live animals or fail to act on dead animals depending on concentration, length of staining time, animal species, presence or absence of physical injury, time of death, and means of death. Thus we are not yet able to use the stain with confidence.

Choosing a control site in the intake forebay is easiest if uniformity can be demonstrated. If distribution is uneven, the causes of the inequality are

likely to act differently on live and dead organisms. This would lead to biased estimates of live/dead ratios. An unequal vertical distribution could be partially remedied by collecting an integrated sample from more than one depth, but collecting a horizontally averaged sample would be more difficult and probably counterproductive. In the early part of 1973 we conducted trials which provide an initial look at the functioning of our sampling system. All intake samples were withdrawn from directly in front of the trash bars using flexible hoses that could be lowered to the desired depth within the 35-ft deep forebay. Turbulence within the discharge bay required that we draw water through a steel pipe. Diameters of both the hose and the pipe were 3 inches. In the first trial, the circulating water pumps had been running for one-half hour at the time the collections were made. In the other trials they had been running for 6 to 8 hours. Results are summarized in Table 1, with the results of a t-test. Tested in Trials 1, 2, and 3 was the hypothesis that mean abundances are equal. In Trial 4, a pairing process was used and the tested hypothesis was that the mean difference between pairs was zero.

TRIAL 1, SUCCESSIVE SAMPLING AT THREE DEPTHS.

On 1 February, four replicates were collected in rapid succession from each of three different depths in the forebay - 33 ft, 17 1/2 ft, and 3 ft. Each sample replicate resulted from 2 min of pumping with the same diaphragm pump and was calculated to be the filtrate of 120 gal. The entire collection process was completed in 1 hr. Differences in species abundances were generally about 10%, and in all but two comparisons they were not statistically significant at the 95% confidence level. Because the circulating pumps had not been running long enough to wash out the sand accumulated in the intake tubes by wave action, the quantity of suspended sand in the samples was large. We decided to dry and

TABLE 1. Mean abundances of zooplankton in numbers per cubic meter, mean weights of suspended sand in grams per cubic meter, and the results of comparisons between samples using a t-test and a percent similarity of community statistic. Samples were collected with a diaphragm pump system on three dates in 1973. Each sample consisted of four replicates.

TRIAL 1: Successive sampling at 3 depths in the intake forebay, 1 Feb. 1973.

	2 ft	17 1/2 ft	33 ft	P	
<i>Nauplii</i>	420	230	270	<.05	(2' > 33')
<i>Cyclops</i>	5800	6300	6000	ns	
<i>Tropocyclops</i>	56	36	35	ns	
<i>Diaptomus</i>	5200	6000	5100	ns	
<i>Limnocalanus</i>	43	65	27	ns	
<i>Harpacticoids</i>	3	16	5	<.05	(2' < 17')
<i>Bosmina</i>	13	17	11	ns	
<i>Daphnia</i>	10	22	19	ns	
<i>Eubosmina</i>	20	19	11	ns	
Other Cladocera	0	6	0	ns	
<i>Asplanchna</i>	26	14	11	ns	
TOTAL	11,600	12,800	11,400	ns	
Sand wt. (g/m ³)	4.0	5.0	8.9	<.01	<.02
PS _c = 96.9	96.7	98.0		(2' < 33')	(17' < 33')

TRIAL 2: Simultaneous sampling at 2 depths in the intake forebay, 15 Feb. 1973.

	5 ft	30 ft	P
<i>Nauplii</i>	220	310	ns
<i>Cyclops</i>	9000	8300	ns
<i>Tropocyclops</i>	9	16	ns
<i>Diaptomus</i>	6800	5900	ns
<i>Limnocalanus</i>	28	11	ns
<i>Harpacticoids</i>	130	150	ns
<i>Bosmina</i>	36	21	ns
<i>Daphnia</i>	37	23	ns
<i>Eubosmina</i>	5	8	ns
Other Cladocera	5	4	ns
<i>Asplanchna</i>	0	0	ns
TOTAL	16,300	14,700	ns
Sand wt (g/m ³)	2.6	5.0	<.05
PS _c = 97.9			

TRIAL 3: Simultaneous sampling at 2 horizontal positions in the intake forebay, 15 Feb. 1973.

	Screen 8	Screen 5	P
Nauplii	210	270	ns
Cyclops	6400	3900	<.01
Tropocyclops	22	26	ns
Diaptomus	6100	3800	<.01
Limnocalanus	77	42	ns
Harpacticoids	160	100	ns
Bosmina	8	3	ns
Daphnia	6	11	ns
Eubosmina	2	1	ns
Other Cladocera	3	2	ns
Asplanchna	7	13	ns
TOTAL	13,000	8,100	<.01
Sand wt. (g/m ³)	5.8	3.9	<.01
PS _c = 98.6			

TRIAL 4: Comparison of intake and discharge bays, 4 April 1973.

	Intake	Discharge	P
Nauplii	1300	1800	ns
Cyclops	2800	2500	ns
Tropocyclops	15	30	ns
Diaptomus	2300	2100	ns
Limnocalanus	3	3	ns
Harpacticoids	86	100	ns
Bosmina	110	10	ns
Daphnia	15	3	ns
Eubosmina	1	1	ns
Other Cladocera	29	33	ns
Asplanchna	9	6	ns
TOTAL	6,700	6,500	ns
Sand wt. (g/m ³)	4.0	15.5	<.001
PS _c = 92.5			

weigh it since it provides information about flow characteristics. Amounts of sand decreased from bottom to top with the 33-ft samples containing significantly greater amounts than both the 17-1/2 ft and the 3-ft samples. The abundance of sand in the upper depths on all the trial dates suggests considerable turbulence.

TRIAL 2, SIMULTANEOUS SAMPLING AT TWO DEPTHS.

On 15 February, four replicates were collected from each of two depths in the forebay--5 ft and 30 ft. Two identically mounted diaphragm pumps were used so that samples could be withdrawn from the two depths simultaneously. Replicates were again 2 min in duration. On this date, only one flowmeter was available, so in this and in Trial 3, abundances had to be calculated assuming that both pumps were drawing water at the same rates. Again differences between the mean abundances of each species were on the order of 10%, and only sand weights were significantly different.

TRIAL 3, SIMULTANEOUS PUMPING AT TWO HORIZONTAL POSITIONS.

On 15 February, four replicates were withdrawn from a depth of 15 ft at two locations in the forebay--in front of travelling screen 8 (the site of Trials 1 and 2) and in front of travelling screen 5 (also the site of Trial 4). At screen 5, 38% fewer animals were collected, a difference that was statistically significant for the abundant taxa. Since this pump was not metered, a difference in pumping rate cannot be ruled out as an explanation. Flow past this site appeared to be greater than at the site in front of screen 8. There was no difference in the species composition of the samples collected at the two locations.

TRIAL 4, COMPARISON OF INTAKE AND DISCHARGE.

On 4 April, four replicates were withdrawn from a depth of 7 ft in the

discharge bay and four were withdrawn from the same depth in the intake forebay. Each sample was 2 min in duration with 154 gal being filtered for each discharge replicate and 132 gal being filtered at the intake location. Collection of each discharge replicate was synchronized with the end of each intake replicate, the 2-min lag being intended to approximate the time for condenser passage. The hypothesis that the mean difference between these pairs would be zero was not contradicted at the 95% confidence level for any of the species.

One of the most encouraging aspects of these results is the sampling precision of the diaphragm pump system. Standard deviations were generally similar to those obtained from replicate vertical hauls taken in the April field survey (Fig. 1) despite the much smaller volume of water that was sampled. This is best explained by the smaller error involved in estimating the quality of water filtered and by a greater uniformity due to turbulent mixing in the intake tubes.

Compositional similarity can be quantified by the statistic PS_c , the percent similarity of community, used for copepod communities by Whittaker and Fairbanks (1958) and described by Greig-Smith (1964).

$$PS_c = 100 - .05E | a' - b' |$$

where a' and b' are, for each species, the respective percentages of the total animals in samples A and B. Values of PS_c fall between 0 (lowest affinity) and 100 (highest). If such an index is used to compare the compositions of samples obtained in these trials, PS_c is usually greater than 95. This is as large or larger than the values that can be obtained by comparing replicate vertical hauls taken at a station in the field.

Because field samples are not taken in the winter, no direct comparison of abundances is possible. However, abundances and species composition were

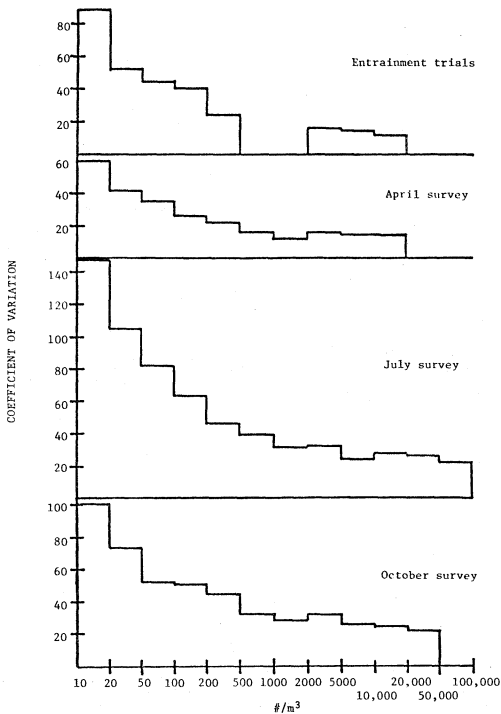


FIGURE 1. Average coefficient of variation for all taxa falling into one of 12 abundance ranges. $c.v. = \frac{s}{\bar{x}} \cdot 100$

consistent with the winter plankton that might have been expected on the basis of the November 1972 and the April 1973 field surveys, and it is fair to regard these samples as representative of the winter fauna in the nearshore region.

FIELD STUDY METHODS

Samples for the 1973 field study were collected monthly from April to October at the stations mapped in Figure 2. Of the 28 stations comprising the major survey grid, 27 were visited on 25 April, 19 July, and 23 October. Of the 8 stations making up the short survey grid, 7 were sampled on dates in the intervening months, 17 May, 20 June, 23 August, and 20 September. The positioning of construction dredges prevented occupation of one station, DC-1, on all of the dates.

Zooplankton were collected with a 0.5 m diameter #10 mesh nylon net (158 μ apertures) towed vertically from near the bottom to the surface at a rate of 0.6 to 0.9 m/sec. A flowmeter mounted in the net mouth measured the volume of water filtered. At each station three hauls were made in succession yielding three sample replicates, each of which was preserved with a sugared formalin solution (Koechies fluid).

In the laboratory, a Folsom plankton splitter was used to divide each replicate as many times as necessary to yield subsamples containing several hundred of the most common taxa. Two such subsamples were then enumerated using a circular glass counting chamber and stereozoom dissecting microscopes. Larger subsamples were examined for rarer taxa. After counting, the subsamples were filtered onto pre-weighed filter papers, oven dried for at least 4 hr at 100°C and weighed on an electrobalance. Uncounted portions of each sample are retained in the Great Lakes Research Division collections.

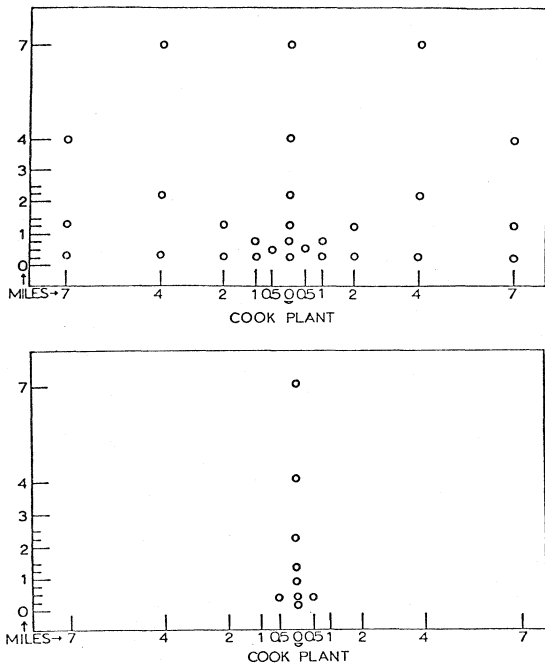


FIGURE 2. The major survey station grid (upper) and the short survey station grid (lower) sampled for zooplankton in 1973.

At most stations identification was carried to genus. Only 3 of the 16 commonly occurring genera contained more than one species. The more time-consuming process of separating the species of these genera (*Cyclops*, *Diaptomus*, and *Daphnia*) was undertaken at 5 stations for each of the long surveys (DC-2, DC-5, DC-6, NDC-7-5, SDC-7-5) and at 3 stations for each of the short surveys (DC-2, DC-5, DC-6). Taxonomy followed Brooks (1959), Deevey and Deevey (1971), Pennak (1963) and Wilson (1959).

A volumetric abundance was calculated for each taxon in each replicate. The three replicates from each station were then averaged to produce the mean abundances given in Tables 2 through 8. These tables also give the standard error associated with each mean, the percentage of the total comprised by each taxon, dry weight expressed on a volumetric basis and a mean dry weight per animal. To avoid rounding errors in future calculations, we have retained more than the maximum of two figures which may be regarded as significant. Aside from the primary data contained in these tables and discussed in the section which follows, information was gathered for several special studies of limited scope, the results of which are presented in the sections on entrainment, night zooplankton, vertical stratification, and natural history.

With the addition of sample replication, these methods are the same as those used in the field studies of 1971 and 1972. A small refinement in counting technique has been the separation of immature copepods by genus. This was quite successful and produced interesting results in the cases of *Eurytemora* and *Limnocalanus*. Early instars of *Epischura* proved difficult to distinguish from *Diaptomus* and are underestimated. Only small numbers of immature *Tropocyclops* were found and these were invariably later instars; early instars of this species seem to be escaping through the net. Some errors in earlier counting

TABLE 2. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 27 stations on April 25, 1973.

Species	DC-2			DC-5			DC-6			NDC-7-5			SDC-7-5		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	6422	530	70.4	6693	526	53.4	6096	221	49.3	8534	990	54.5	3773	77	40.0
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	498	59	5.5	1179	83	9.4	748	79	6.0	1711	79	10.9	938	96	9.7
<i>Cyclops bicuspidatus thomasi</i>	196	22	2.1	448	48	3.6	1072	39	8.7	600	59	3.8	963	120	0.9
<i>Cyclops vernalis</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Tropocyclops prasinus mexicanus</i>	3	3	0.0	15	8	0.1	10	1	0.1	13	5	0.1	11	5	0.1
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	819	90	9.0	1987	176	15.9	1035	100	8.4	2438	253	15.6	904	58	9.3
<i>Diaptomus ashlandi</i>	568	47	6.2	1056	48	8.4	1648	74	13.3	977	172	6.2	1849	176	19.1
<i>Diaptomus minutus</i>	406	19	4.5	460	17	3.7	757	36	6.1	295	8	1.9	564	108	5.8
<i>Diaptomus oregonensis</i>	9	6	0.0	56	27	0.4	456	62	3.7	253	80	1.6	194	29	2.0
<i>Diaptomus stellis</i>	0	0	0.0	17	5	0.1	53	3	0.4	9	2	0.1	21	2	0.2
<i>Epiachura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epiachura lacustris</i>	31	16	0.3	28	6	0.2	3	3	0.0	7	3	0.0	0	0	0.0
<i>Eurytemora affinis</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	23	16	0.3	490	28	3.9	396	36	3.2	736	40	4.7	426	5	4.4
<i>Limnocalanus macrurus</i>	0	0	0.0	0	0	0.0	25	9	0.2	7	2	0.0	1	1	0.0
Harpacticoid copepods															
<i>Canthocamptus</i> sp	5	3	0.0	0	0	0.0	13	10	0.1	5	5	0.0	6	3	0.1
Cladocerans															
<i>Bosmina longirostris</i>	77	9	0.8	67	32	0.5	26	3	0.2	36	4	0.2	16	4	0.2
<i>Ceriodaphnia quadrangula</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus sphaericus</i>	2	2	0.0	2	2	0.0	0	0	0.0	0	0	0.0	1	1	0.0
<i>Daphnia galeata mendotae</i>	25	6	0.3	18	2	0.1	6	3	0.0	29	6	0.2	6	3	0.1
<i>Daphnia retrocurva</i>	25	3	0.3	1	1	0.0	0	0	0.0	7	2	0.0	0	0	0.0
<i>Diaphanosoma leuckertbergianum</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina coregoni</i>	0	0	0.0	2	2	0.0	5	1	0.0	6	4	0.0	6	2	0.1
<i>Holopedium gibberum</i>	3	3	0.0	2	2	0.0	0	0	0.0	0	0	0.0	1	1	0.0
<i>Leptodora kindtii</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphepus pediculus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers															
<i>Asplanchna priodonta</i>	3	3	0.0	1	1	0.0	2	2	0.0	3	3	0.0	1	1	0.0
Total	9118	658		12527	324		12366	438		15666	1378		9685	559	
Dry wt (mg/m ³)	20	3		22	1		48	13		24	2		28	4	
Dry wt (ug/individual)	2.2	0.3		1.9	0.3		3.9	1.2		1.5	0.2		2.9	0.4	

TABLE 2 continued. April 25, 1973.

Genus	DC-3			DC-4			NDC-5-2			SDC-5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	5780	739	63.8	7679	395	60.5	6384	760	73.8	6178	253	74.1
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	448	91	4.9	423	66	3.3	182	28	2.1	197	14	2.4
<i>Cyclops</i> C ₆	373	8	4.1	489	28	3.8	258	14	3.0	307	7	3.7
<i>Tropocyclops</i>	5	2	0.0	2	2	0.0	15	3	0.2	18	5	0.2
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	893	89	9.9	1176	221	9.3	540	77	6.2	581	51	7.0
<i>Diaptomus</i> C ₆	1384	180	15.3	2702	917	21.3	1033	46	12.0	785	121	9.4
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	37	14	0.4	54	9	0.4	30	4	0.3	47	5	0.6
<i>Eurytemora</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	26	6	0.3	101	30	0.8	0	0	0.0	1	1	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	4	3	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans												
<i>Bosmina</i>	62	2	0.7	36	23	0.3	172	23	2.0	188	25	2.3
<i>Gerridaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	5	2	0.0	11	3	0.1	2	2	0.0	3	1	0.0
<i>Daphnia</i>	34	3	0.4	21	9	0.2	32	4	0.4	24	2	0.3
<i>Diaphanosoma</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	5	2	0.0	0	0	0.0	5	3	0.1	3	1	0.0
<i>Holopedium</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers												
<i>Asplanchna</i>	2	2	0.0	8	4	0.1	3	2	0.0	2	1	0.0
Total	9057	1026		12703	1560		8655	864		8335	397	
Dry wt (mg/m ³)												
Dry wt (µg/individual)												

TABLE 2 continued. April 25, 1973.

Genus	NDC-1-1			NDC-1-2			NDC-2-1			NDC-2-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	5177	370	79.3	6068	266	64.2	3541	251	77.0	7132	461	71.7
Cyclopoid copepods	245	55	3.8	559	31	6.0	279	7	6.1	610	33	6.1
<i>Cyclops</i> C ₁ -C ₅	258	50	4.0	379	43	4.0	117	6	2.5	190	36	1.9
<i>Cyclops</i> C ₆	14	8	0.2	5	1	0.1	14	8	0.3	7	2	0.1
<i>Tropocyclops</i>												
Calanoid copepods	331	65	5.1	927	36	9.8	305	21	6.6	1079	88	10.8
<i>Diaptomus</i> C ₁ -C ₅	255	13	3.9	1319	127	14.0	148	27	3.2	771	45	7.8
<i>Diaptomus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	68	12	1.0	27	3	0.3	64	6	1.4	41	15	0.4
<i>Eurytemora</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₆	0	0	0.0	7	1	0.1	0	0	0.0	26	6	0.3
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	1	1	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	1	1	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	0	0	0.0	3	2	0.0	0	0	0.0	1	1	0.0
Cladocerans												
<i>Bosmina</i>	176	19	2.7	72	5	0.8	125	24	2.7	43	8	0.4
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	0	0	0.0	2	1	0.0	0	0	0.0	0	0	0.0
<i>Daphnia</i>	0	0	0.0	70	17	0.7	0	0	0.0	30	8	0.3
<i>Diaphanosoma</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	1	1	0.0	4	2	0.0	0	0	0.0	8	5	0.1
<i>Holopedium</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers												
<i>Asplanchna</i>	3	2	0.0	8	5	0.1	0	0	0.0	4	2	0.0
Total	6531	524		9452	53		4602	282		9946	602	
Dry wt (mg/m ³)												
Dry wt (µg/individual)												

TABLE 2 continued. April 25, 1973.

Genus	NDC-4-1			NDC-4-3			NDC-4-4			NDC-7-1			NDC-7-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	4344	614	76.8	8397	279	74.2	5281	1013	43.5	4003	59	50.4	5907	581	62.1
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	214	23	3.8	784	53	6.9	877	65	7.2	767	44	9.7	397	38	4.2
<i>Cyclops</i> C ₆	92	33	1.6	151	22	1.3	1556	40	12.8	692	62	8.7	375	45	3.9
<i>Tropocyclops</i>	12	2	0.2	7	1	0.1	6	6	0.0	7	7	0.1	7	2	0.1
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	513	58	9.1	1096	95	9.7	1449	20	11.9	771	100	9.7	1544	172	16.2
<i>Diaptomus</i> C ₆	142	20	2.5	779	24	6.9	2611	138	21.5	1238	55	15.6	1187	141	12.5
<i>Epiischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epiischura</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	49	16	0.9	19	5	0.2	73	33	0.6	166	18	2.1	15	2	0.2
<i>Eurytemora</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	22	1	0.2	199	3	1.6	0	0	0.0	8	1	0.1
<i>Limnocalanus</i> C ₆	0	0	0.0	1	1	0.0	15	5	0.1	0	0	0.0	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	1	1	0.0	5	5	0.1	2	2	0.0
Cladocerans															
<i>Boeemia</i>	283	31	5.0	36	9	0.3	29	5	0.2	207	43	2.6	38	6	0.4
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	1	1	0.0	2	2	0.0	6	3	0.0	72	6	0.9	11	3	0.1
<i>Daphnia</i>	2	1	0.0	14	1	0.1	12	1	0.1	3	3	0.0	8	2	0.1
<i>Daphnoscema</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	1	1	0.0	4	3	0.0	10	6	0.1	4	3	0.0	1	1	0.0
<i>Heptodonta</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers															
<i>Asplanchna</i>	4	1	0.1	4	1	0.0	0	0	0.0	7	1	0.1	3	3	0.0
Total	5658	725		11320	376		12131	941		7941	153		9504	632	
Dry wt (mg/m ³)															
Dry wt (µg/individual)															

TABLE 2 continued. April 25, 1973.

Genus	SDC-1-1			SDC-1-2			SDC-2-1			SDC-2-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	4978	171	72.9	5982	790	71.1	3428	70	70.2	5715	471	68.1
Cyclopoid copepods	223	46	3.3	288	96	3.4	184	27	3.8	232	29	2.8
<i>Cyclops</i> C ₁ -C ₅	290	57	4.2	227	46	2.7	124	18	2.5	192	19	2.3
<i>Cyclops</i> C ₆	12	7	0.2	7	1	0.1	4	2	0.1	5	5	0.1
<i>Tropocyclops</i>												
Calanoid copepods	398	50	5.8	830	59	9.9	345	41	7.1	916	44	10.9
<i>Diaptomus</i> C ₁ -C ₅	673	105	9.6	874	204	10.4	522	28	10.7	1119	63	13.3
<i>Diaptomus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	44	8	0.6	32	0	0.0	64	7	1.3	40	9	0.5
<i>Eurytemora</i> C ₁ -C ₅	1	1	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₆	1	1	0.0	0	0	0.0	0	0	0.0	36	3	0.4
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods	0	0	0.0	19	14	0.2	1	1	0.0	0	0	0.0
<i>Canthocamptus</i>												
Cladocerans	170	18	2.5	91	18	1.1	192	35	3.9	72	8	0.9
<i>Bosmina</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Ceriodaphnia</i>	11	4	0.2	1	1	0.0	1	1	0.0	0	0	0.0
<i>Chydorus</i>	11	3	0.2	53	8	0.6	8	2	0.2	52	17	0.6
<i>Daphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Diaphanosoma</i>	0	0	0.0	5	3	0.1	5	3	0.1	5	2	0.1
<i>Eubosmina</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Holopedium</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers	14	7	0.2	3	3	0.0	6	3	0.1	0	0	0.0
<i>Asplanchna</i>												
Total	6826	443		8414	833		4885	141		8384	400	
Dry wt (mg/m ³)												
Dry wt (μg/individual)												

TABLE 2 continued. April 25, 1973.

Genus	SDC-4-1			SDC-4-3			SDC-4-4			SDC-7-1			SDC-7-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	2293	249	70.1	7915	1785	61.0	2787	254	38.3	3056	412	59.9	5139	514	66.2
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	71	13	2.2	483	158	3.7	244	47	3.4	124	18	2.4	232	6	3.0
<i>Cyclops</i> C ₆	33	6	1.0	566	117	4.4	1008	119	13.9	206	35	4.0	411	58	5.3
<i>Tropocyclops</i>	2	1	0.1	16	8	0.1	6	1	0.1	8	1	0.2	19	5	0.2
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	205	3	6.3	1390	247	10.7	413	77	5.7	329	58	6.4	861	102	11.1
<i>Diaptomus</i> C ₆	511	50	15.6	2306	383	17.8	2705	464	37.2	1170	47	22.9	912	48	11.7
<i>Eutima</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eutima</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	29	1	0.9	50	15	0.4	12	7	0.2	42	5	0.8	11	2	0.1
<i>Eurytemora</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	74	38	0.6	69	12	0.9	2	2	0.0	18	3	0.2
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	14	6	0.2	0	0	0.0	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	32	32	0.2	1	1	0.0	0	1	0.0	11	3	0.1
Cladocerans															
<i>Bosmina</i>	114	10	3.5	114	48	0.9	11	5	0.2	129	31	2.5	51	4	0.7
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	1	1	0.0	0	0	0.0	0	0	0.0	2	1	0.0	2	1	0.0
<i>Daphnia</i>	8	2	0.2	0	0	0.0	4	2	0.1	26	8	0.5	32	2	0.4
<i>Diaphanosoma</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	1	1	0.0	0	0	0.0	1	1	0.0	0	0	0.0	0	0	0.0
<i>Holopedium</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	1	1	0.0
<i>Polyphehus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	1	0.0
Rotifers															
<i>Asplanchna</i>	2	1	0.1	8	8	0.1	0	0	0.0	3	2	0.1	1	1	0.0
Total	3271	306		12968	2623		7273	793		5098	431		7766	725	
Dry wt (mg/m ³)															
Dry wt (ug/individual)															

TABLE 3. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 7 stations on May 17, 1973.

Species	DC-2			DC-5			DC-6		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	6146	375	36.4	19373	930	41.1	9065	411	47.6
Cyclopoid copepods	4231	469	25.0	7517	279	16.0	1411	8	7.4
<i>Cyclops</i> C ₁ -C ₅	76	14	0.4	454	12	1.0	790	153	4.1
<i>Cyclops bicuspidatus thomasi</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Cyclops vernalis</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Tropocyclops prasinus mexicanus</i>	2	2	0.0	13	4	0.0	24	0	0.1
Calanoid copepods	5733	404	33.9	17385	513	36.9	5403	54	28.4
<i>Diaptomus</i> C ₁ -C ₅	17	6	0.1	507	50	1.1	1053	67	5.5
<i>Diaptomus ashlandi</i>	37	9	0.2	394	39	0.8	381	20	2.0
<i>Diaptomus minutus</i>	15	5	0.1	113	30	0.2	344	104	1.8
<i>Diaptomus oregonensis</i>	0	0	0.0	0	0	0.0	30	12	0.1
<i>Diaptomus sicilis</i>	24	13	0.1	14	14	0.0	0	0	0.0
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura lacustris</i>	42	9	0.2	13	7	0.0	12	12	0.1
<i>Eurytemora</i> C ₁ -C ₅	2	2	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora affinis</i>	74	21	0.4	522	81	1.1	333	57	1.7
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	21	8	0.1
<i>Limnocalanus macrurus</i>	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods	92	12	0.5	10	10	0.0	0	0	0.0
<i>Canthocamptus</i> sp	320	99	1.9	677	76	1.4	156	73	0.8
Cladocerans	0	0	0.0	0	0	0.0	0	0	0.0
<i>Bosmina longirostris</i>	37	9	0.2	3	3	0.0	3	3	0.0
<i>Ceriodaphnia quadrangula</i>	5	5	0.0	26	13	0.1	3	3	0.0
<i>Chydorus sphaericus</i>	3	2	0.0	13	7	0.0	0	0	0.0
<i>Daphnia galeata mendotae</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Daphnia retrocurva</i>	12	8	0.1	17	4	0.0	0	0	0.0
<i>Daphniasoma leuchtenbergianum</i>	0	0	0.0	13	8	0.0	3	3	0.0
<i>Eubosmina coregoni</i>	0	0	0.0	3	3	0.0	0	0	0.0
<i>Holopedium gibberum</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora kindtii</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus pediculus</i>	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers	25	12	0.1	38	24	0.1	6	6	0.0
<i>Asplanchna priodonta</i>	16896	1337		47105	1655		19036	810	
Total	53	14		62	5		70	-	
Dry wt (mg/m ³)	3.3	0.7		1.3	0.1		3.5	-	
Dry wt (ug/individual)									

TABLE 3 continued. May 17, 1973.

Genus	DC-3			DC-4			NDC-5-2			SDC-5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	8169	691	36.3	8767	594	37.6	1619	28	35.3	1221	115	45.7
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	6140	294	27.3	3674	214	15.7	1869	345	40.7	569	94	21.3
<i>Cyclops</i> C ₆	1536	432	6.8	504	51	2.2	58	16	1.3	50	20	1.9
<i>Tropocyclops</i>	5	5	0.0	2	2	0.0	24	8	0.5	5	5	0.2
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	6131	2380	27.2	9235	197	39.6	532	119	11.6	472	70	17.7
<i>Diaptomus</i> C ₆	101	28	0.4	279	72	1.2	15	5	0.3	13	13	0.5
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	18	13	0.1	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	20	13	0.1	43	5	0.2	27	5	0.6	54	8	2.0
<i>Eurytemora</i> C ₆	10	2	0.0	0	1	0.0	6	1	0.1	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	62	16	0.3	67	17	0.3	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	45	23	0.2	56	-	0.3	14	6	0.3	14	9	0.5
Cladocerans												
<i>Bosmina</i>	176	39	0.8	555	77	2.4	175	12	3.8	113	40	4.2
<i>Ceriodaphnia</i>	1	1	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	9	6	0.0	17	0	0.1	94	13	2.0	94	17	3.5
<i>Daphnia</i>	59	5	0.3	60	13	0.3	0	0	0.0	0	0	0.0
<i>Diaphanosoma</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	20	14	0.1	28	25	0.1	22	6	0.5	13	4	0.5
<i>Holopedium</i>	1	1	0.0	2	2	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	2	2	0.0	2	2	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers												
<i>Asplanchna</i>	6	1	0.0	17	9	0.1	133	23	2.9	54	16	2.0
Total	22500	3465		23328	729		4589	529		2673	321	
Dry wt (mg/m ³)												
Dry wt (µg/individual)												

TABLE 4. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 7 stations on June 20, 1973.

Species	DC-2			DC-5			DC-6		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	11578	367	24.4	5295	319	9.2	5449	95	10.1
Cyclopoid copepods	8862	1106	18.6	5507	410	9.6	15551	710	28.8
<i>Cyclops</i> C ₁ -C ₅	0	0	0.0	2013	104	3.5	3183	210	5.9
<i>Cyclops bicuspidatus thomasi</i>	19	12	0.0	0	0	0.0	0	0	0.0
<i>Cyclops vernalis</i>	24	12	0.0	0	0	0.0	38	2	0.1
Tropocyclops prasinus mexicanus									
Calanoid copepods	9708	57	20.4	9943	235	17.3	20045	1349	37.1
<i>Diaptomus</i> C ₁ -C ₅	75	21	0.2	1848	72	3.2	3387	543	6.3
<i>Diaptomus ashlandi</i>	494	75	1.0	235	38	0.4	401	89	0.7
<i>Diaptomus minutus</i>	12	12	0.0	115	12	0.2	102	24	0.2
<i>Diaptomus oregonensis</i>	0	0	0.0	26	10	0.0	58	21	0.1
<i>Diaptomus sicilis</i>	6	6	0.0	5	5	0.0	0	0	0.0
<i>Eutichura</i> C ₁ -C ₅	0	0	0.0	5	5	0.0	7	7	0.0
<i>Eutichura lacustris</i>	324	106	0.7	32	18	0.1	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	0	0	0.0	21	10	0.0	18	10	0.0
<i>Eurytemora affinis</i>	0	0	0.0	26	13	0.0	66	36	0.1
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	52	26	0.1	268	46	0.5
<i>Limnocalanus macrurus</i>									
Harpacticoid copepods	0	0	0.0	0	0	0.0	0	0	0.0
<i>Canthocamptus</i> sp									
Cladocerans	14913	1402	31.4	31439	2621	54.6	5147	248	9.5
<i>Bosmina longirostris</i>	6	6	0.0	0	0	0.0	0	0	0.0
<i>Ceriodaphnia quadrangula</i>	6	6	0.0	11	5	0.0	0	0	0.0
<i>Chydorus sphaericus</i>	0	0	0.0	5	5	0.0	56	8	0.1
<i>Daphnia galeata mendotae</i>	12	6	0.0	43	14	0.1	88	36	0.2
<i>Daphnia retrocurva</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Diaphanosoma leuchtentbergianum</i>	6	6	0.0	0	0	0.0	11	12	0.0
<i>Eubosmina coregoni</i>	0	0	0.0	0	0	0.0	7	7	0.0
<i>Holopedium gibberum</i>	0	0	0.0	11	10	0.0	0	0	0.0
<i>Leptodora kindtii</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus pediculus</i>	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers									
<i>Asplanchna priodonta</i>	1470	601	3.1	917	137	1.6	114	69	0.2
Total	47518	865		57548	3509		53995	1413	
Dry wt (mg/m ³)	60	12		105	21		113	16	
Dry wt (ug/individual)	1.2	0.2		1.8	0.3		2.1	0.2	

TABLE 4 continued. June 20, 1973.

Genus	DC-3			DC-4			NDC-5-2			SDC-5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	9160	314	20.8	7311	773	13.6	4545	2348	28.0	5245	833	35.3
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	5985	226	13.6	5612	775	10.4	1406	475	8.7	1619	482	10.9
<i>Cyclops</i> C ₆	2423	342	5.5	2543	211	4.7	119	39	0.7	143	99	1.0
<i>Tropocyclops</i>	18	6	0.0	0	0	0.0	7	7	0.0	9	9	0.1
Galanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	10382	1059	23.6	15305	1593	28.4	3536	464	21.8	2674	242	18.0
<i>Diaptomus</i> C ₆	3621	365	8.2	4193	559	7.8	689	113	4.2	923	232	6.2
<i>Epischura</i> C ₁ -C ₅	9	9	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	2	2	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	123	24	0.3	60	41	0.1	721	129	4.4	804	53	5.4
<i>Eurytemora</i> C ₆	0	0	0.0	15	8	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	6	3	0.0	8	8	0.0	0	0	0.0	1	1	0.0
<i>Limnocalanus</i> C ₆	4	5	0.0	22	12	0.0	0	0	0.0	1	1	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	4	3	0.0
Cladocerans												
<i>Boatina</i>	11569	469	26.3	18157	1514	33.7	5016	610	31.0	3253	790	21.9
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	1	1	0.0
<i>Glydorus</i>	22	16	0.0	21	12	0.0	39	8	0.2	28	7	0.2
<i>Daphnia</i>	95	37	0.2	148	51	0.3	0	0	0.0	1	1	0.0
<i>Diaphanosoma</i>	0	0	0.0	0	0	0.0	0	0	0.0	1	1	0.0
<i>Eubosmina</i>	10	7	0.0	36	8	0.1	11	6	0.1	19	11	0.1
<i>Holopedium</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Leptodora</i>	4	5	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus</i>	2	2	0.0	0	0	0.0	16	8	0.1	15	8	0.1
Rotifers												
<i>Asplanchna</i>	381	69	0.9	477	232	0.9	69	35	0.4	123	32	0.8
Total	44057	2302		53907	3623		16226	3753		14866	2320	
Dry wt (mg/m ³)							50	-		36	2	
Dry wt (µg/individual)							4.8	-		2.9	0.0	

TABLE 5. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 27 stations on July 19, 1973.

Species	DC-2			DC-5			DC-6			NDC-7-5			SDC-7-5		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	17869	988	24.7	7927	80	14.9	7020	474	13.8	14434	1863	17.3	8810	639	18.8
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	11705	744	16.2	6213	325	11.7	6939	338	13.6	7903	54	9.5	7056	271	15.0
<i>Cyclops bicuspidatus thomasi</i>	43	21	0.1	2017	168	3.8	2146	47	4.2	2508	221	3.0	1412	37	3.0
<i>Cyclops vernalis</i>	6	6	0.0	30	29	0.1	0	0	0.0	76	38	0.1	20	20	0.0
<i>Tropocyclops prasinus mexicanus</i>	994	195	1.4	325	53	0.6	210	13	0.4	517	98	0.6	244	78	0.5
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	8279	1490	11.4	21012	875	39.5	13355	786	26.2	34005	1167	40.7	10446	544	22.3
<i>Diaptomus ashlandi</i>	199	72	0.3	2514	135	4.7	1108	68	2.2	4000	151	4.8	1062	104	2.3
<i>Diaptomus minutus</i>	991	77	1.4	1586	43	3.0	925	114	1.8	2888	313	3.5	514	152	1.1
<i>Diaptomus oregonensis</i>	103	37	0.1	372	56	0.7	208	96	0.4	689	41	0.8	102	19	0.2
<i>Diaptomus stollis</i>	0	0	0.0	36	21	0.1	4	7	0.1	134	95	0.2	0	0	0.0
<i>Eutichura</i> C ₁ -C ₅	6	6	0.0	25	13	0.0	16	10	0.0	19	19	0.0	103	22	0.2
<i>Eutichura lacustris</i>	3	3	0.0	0	0	0.0	4	4	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	2118	89	2.9	50	13	0.1	49	13	0.1	57	19	0.1	407	157	0.9
<i>Eurytemora affinis</i>	341	55	0.5	69	31	0.1	17	12	0.0	0	0	0.0	126	1	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus macrurus</i>	0	0	0.0	191	28	0.4	73	7	0.1	115	18	0.1	31	10	0.1
Haracticoid copepods															
<i>Canthocamptus</i> sp	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans															
<i>Bosmina longirostris</i>	26510	386	36.6	9160	621	17.2	17311	843	34.0	14007	369	16.8	15761	1472	33.6
<i>Ceriodaphnia quadrangula</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus sphaericus</i>	19	1	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Daphnia galeata mendotae</i>	30	21	0.0	179	17	0.3	92	9	0.2	211	18	0.2	20	20	0.0
<i>Daphnia retrocurva</i>	922	89	1.3	339	79	0.6	396	73	0.8	613	117	0.7	205	4	0.4
<i>Diaphanosoma leuchtenbergianum</i>	22	11	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina coregoni</i>	105	6	0.1	94	47	0.2	163	58	0.3	345	116	0.4	62	21	0.1
<i>Holopedium gibberum</i>	18	18	0.0	104	38	0.2	81	2	0.2	58	20	0.1	0	0	0.0
<i>Leptodora kindtii</i>	37	1	0.0	24	12	0.0	16	10	0.0	10	9	0.0	0	0	0.0
<i>Polyphemus pediculus</i>	196	37	0.3	30	16	0.1	52	21	0.1	115	37	0.1	103	22	0.2
Rotifers															
<i>Asplanchna priodonta</i>	1862	271	2.6	832	65	1.6	672	44	1.3	843	81	1.0	450	33	1.0
Total	72427	1815		53127	1032		50901	2521		83541	3731		46928	2128	
Dry wt (mg/m ³)	114	7		115	21		78	4		150	9		89	12	
Dry wt (ug/individual)	1.5	0.1		2.2	0.4		1.6	0.1		1.8	0.0		1.9	0.2	

TABLE 5 continued. July 19, 1973.

Genus	DC-3			DC-4			NDC-5-2			SDC-5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	15365	2670	22.8	15536	5092	21.5	16367	4305	25.1	9823	2210	24.7
Cyclopoid copepods	7018	523	10.4	6708	1370	9.3	9453	2600	14.5	3958	1315	10.0
<i>Cyclops</i> C ₁ -C ₅	129	2	0.2	462	69	0.6	175	169	0.3	89	72	0.2
<i>Cyclops</i> C ₆	153	42	0.2	141	141	0.2	1620	169	2.5	454	130	1.1
<i>Tropocyclops</i>												
Calanoid copepods	12047	860	17.9	20103	4487	27.8	10585	3117	16.2	8042	2569	20.2
<i>Diaptomus</i> C ₁ -C ₅	2694	386	4.0	3236	802	4.5	2013	756	3.1	654	101	1.6
<i>Diaptomus</i> C ₆	0	0	0.0	8	8	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₁ -C ₅	9	9	0.0	16	16	0.0	9	9	0.0	10	10	0.0
<i>Epischura</i> C ₆	468	269	0.7	367	141	0.5	1666	407	2.6	998	338	2.5
<i>Eurytemora</i> C ₁ -C ₅	343	105	0.5	175	66	0.2	53	27	0.1	39	19	0.1
<i>Eurytemora</i> C ₆	9	9	0.0	22	23	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	50	50	0.1	62	42	0.1	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆												
Harpacticoid copepods	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Canthocamptus</i>												
Cladocerans	27527	3296	40.9	23704	5741	32.8	20282	6763	31.1	13911	1926	35.0
<i>Bosmina</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Ceriodaphnia</i>	17	17	0.0	8	8	0.0	27	16	0.0	0	0	0.0
<i>Chydorus</i>	694	125	1.0	586	355	0.8	1229	163	1.9	459	114	1.6
<i>Daphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	12	9	0.0
<i>Diaphanosoma</i>	76	43	0.1	99	29	0.1	75	40	0.1	62	13	0.2
<i>Eubosmina</i>	42	42	0.1	109	88	0.2	66	14	0.1	36	18	0.1
<i>Holopedium</i>	26	15	0.0	47	36	0.1	71	9	0.1	19	19	0.0
<i>Leptodora</i>	93	40	0.1	122	110	0.2	367	28	0.6	218	13	0.5
<i>Polyphehus</i>												
Rotifers	584	152	0.9	825	242	1.1	1139	318	1.7	949	212	2.4
<i>Asplanchna</i>												
Total	67355	6984		72336	19088		65207	18710		39736	8906	
Dry wt (mg/m ³)	170	30		159	13		115	32		88	63	
Dry wt (µg/individual)	2.5	0.3		2.4	0.4		1.7	0.1		1.9	0.8	

TABLE 5 continued. July 19, 1973.

Genus	NDC-1-1			NDC-1-2			NDC-1-1			NDC-2-1			NDC-2-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	15275	470	26.5	8032	992	17.9				5251	934	26.1	10259	992	24.2
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	7859	309	13.6	5824	909	13.0				2321	893	11.6	3696	62	8.7
<i>Cyclops</i> C ₆	127	89	0.2	112	21	0.2				41	15	0.2	127	41	0.3
<i>Tropocyclops</i>	710	70	1.2	350	50	0.8				298	3	1.5	264	40	0.6
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	6361	430	11.0	5374	1361	12.0				877	286	4.4	6768	442	16.0
<i>Diaptomus</i> C ₆	1885	415	3.3	1406	204	3.1				366	43	1.8	1672	106	3.9
<i>Epiplatys</i> C ₁ -C ₅	0	0	0.0	0	0	0.0				0	0	0.0	0	0	0.0
<i>Epiplatys</i> C ₆	0	0	0.0	0	0	0.0				0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	1267	237	2.2	636	139	1.4				833	377	4.1	1007	248	2.4
<i>Eurytemora</i> C ₆	90	49	1.6	119	43	0.3				69	51	0.3	247	29	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0				0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0				13	10	0.1	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0				0	0	0.0	0	0	0.0
Cladocerans															
<i>Bosmina</i>	22146	2464	38.4	19962	4223	44.5				9020	954	44.9	15567	1471	36.8
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0				0	0	0.0	0	0	0.0
<i>Chydorus</i>	33	20	0.1	52	10	0.1				3	2	0.0	46	32	0.1
<i>Daphnia</i>	307	69	0.5	421	66	0.9				160	85	0.8	595	20	1.4
<i>Diaphanosoma</i>	0	0	0.0	0	0	0.0				2	2	0.0	10	10	0.0
<i>Eubosmina</i>	16	16	0.0	79	22	0.2				58	13	0.3	37	22	0.1
<i>Holopedium</i>	10	10	0.0	28	14	0.1				8	2	0.0	48	3	0.1
<i>Leptodora</i>	61	63	0.1	28	14	0.1				22	9	0.1	9	9	0.0
<i>Polyphemus</i>	356	77	0.6	282	117	0.6				178	-	0.9	142	23	0.3
Rotifers															
<i>Asplanchna</i>	1074	108	1.9	2165	214	4.8				566	55	2.8	1764	159	4.2
Total	57593	3175		44879	7400					20079	3439		42300	2525	
Dry wt (mg/m ³)	87	3		199	-					45	18		108	-	
Dry wt (µg/individual)	1.5	0.1		3.3	-					2.0	0.5		2.7	-	

TABLE 5 continued. July 19, 1973.

Genus	NDC-4-1			NDC-4-3			NDC-4-4			NDC-7-1			NDC-7-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	6374	1239	19.4	17843	4525	25.1	5950	1443	9.1	3317	633	8.3	22243	1930	22.4
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	1467	419	4.5	3802	968	5.3	8567	725	13.1	1611	176	4.0	4695	462	4.7
<i>Cyclops</i> C ₆	130	73	0.4	261	95	0.4	4405	1255	6.7	237	145	0.6	511	57	0.5
<i>Tropocyclops</i>	367	363	1.1	421	210	0.6	260	28	0.4	771	218	1.9	812	237	0.8
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	2573	299	7.8	19842	5229	27.9	17529	2192	26.8	4229	144	10.6	16114	793	16.2
<i>Diaptomus</i> C ₆	1944	95	5.9	2629	613	3.7	4616	1192	7.1	2118	333	5.3	3813	244	3.8
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	8	7	0.0	32	32	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	482	482	1.5	180	151	0.2	14	14	0.0	847	158	2.1	881	312	0.9
<i>Eurytemora</i> C ₆	0	0	0.0	60	30	0.1	14	7	0.0	70	47	0.2	233	51	0.2
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	55	55	0.1	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	18	18	0.0	28	28	0.0	205	65	0.3	0	0	0.0	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans															
<i>Bosmina</i>	15546	5108	47.3	22191	5215	31.2	21739	3313	33.2	23966	3409	59.8	43710	3057	44.0
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	6	6	0.0	0	0	0.0
<i>Chydorus</i>	23	23	0.1	4	4	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Daphnia</i>	254	56	0.8	662	263	0.9	1414	284	2.2	660	254	1.6	1723	59	1.7
<i>Diaphanosoma</i>	3	2	0.0	8	8	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	136	74	0.4	170	63	0.2	42	21	0.1	52	27	0.1	272	173	0.3
<i>Holopedium</i>	57	41	0.2	249	117	0.3	155	28	0.2	123	38	0.3	289	43	0.3
<i>Leptodora</i>	18	9	0.0	0	0	0.0	79	69	0.1	6	6	0.0	10	10	0.0
<i>Polyphehus</i>	895	-	2.7	281	8	0.4	63	20	0.1	679	-	1.7	809	441	0.8
Rotifers															
<i>Asplanchna</i>	2545	430	7.7	2405	505	3.4	264	171	0.4	1345	256	3.6	3078	178	3.1
Total	32856	8277		71074	16849		65372	8828		40042	5130		99245	979	
Dry wt (mg/m ³)	40	-		131	26		130	10		123	14		436	131	
Dry wt (µg/individual)	0.8	-		1.9	0.1		2.1	0.4		3.3	1.0		4.5	1.4	

TABLE 5 continued. July 19, 1973

Genus	SDC-1-1			SDC-1-2			SDC-2-1			SDC-2-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	6099	2002	13.1									
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	5326	1337	11.4	9466	2039	12.0	1547	622	6.9	3741	2160	5.6
<i>Cyclops</i> C ₆	30	29	0.1	114	69	0.1	20	12	0.1	230	69	0.3
<i>Tropocyclops</i>	479	74	1.0	428	93	0.5	504	180	2.2	255	103	0.4
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	5090	307	10.9	12218	3366	15.5	3901	1537	17.2	11229	3474	16.9
<i>Diaptomus</i> C ₆	904	237	1.9	3220	1275	4.1	574	73	2.5	1890	524	2.8
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	19	10	0.0	24	24	0.0	0	0	0.0	21	10	0.0
<i>Eurytemora</i> C ₁ -C ₅	1350	95	2.9	2303	369	2.9	746	129	3.3	1819	570	2.7
<i>Eurytemora</i> C ₆	39	20	0.1	443	46	0.6	25	19	0.1	219	115	0.3
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	24	24	0.0	6	6	0.0	15	16	0.1	21	10	0.0
<i>Haracticoid copepods</i>												
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans												
<i>Bosmina</i>	25637	2576	55.1	32078	8839	40.6	10099	3063	44.7	32139	9415	48.5
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	18	18	0.0	0	0	0.0	14	14	0.1	5	5	0.0
<i>Daphnia</i>	384	14	0.8	927	326	1.2	74	36	0.3	734	255	1.1
<i>Diaphanosoma</i>	6	6	0.0	12	12	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	41	42	0.1	45	29	0.1	7	7	0.0	64	6	0.1
<i>Holopedium</i>	60	41	0.1	31	17	0.0	4	5	0.0	37	19	0.1
<i>Leptodora</i>	0	0	0.0	12	11	0.0	0	0	0.0	21	22	0.0
<i>Polyphemus</i>	103	81	0.2	208	40	0.3	185	-	0.8	81	81	0.1
Rotifers												
<i>Asplanchna</i>	907	142	1.9	599	281	0.8	512	76	2.3	337	92	0.5
Total	46526	6735		79030	20662		22614	6757		66321	17767	
Dry wt (mg/m ³)	97	13		223	29		53	5		190	40	
Dry wt (µg/individual)	2.1	0.4		2.3	0.2		3.4	0.7		3.5	1.3	

TABLE 5 continued. July 19, 1973.

Genus	SDC-4-1			SDC-4-3			SDC-4-4			SDC-7-1			SDC-7-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	3908	1480	12.4	9826	983	21.6	10916	879	11.0	1960	184	13.5	26845	348	29.6
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	3476	1931	11.0	5467	230	12.0	12850	853	12.9	809	68	5.6	14195	1203	15.6
<i>Cyclops</i> C ₆	204	85	0.6	849	197	1.9	7882	2210	7.9	77	10	0.5	910	152	1.0
<i>Tropocyclops</i>	130	68	0.4	138	61	0.3	200	5	0.2	282	54	1.9	316	116	0.3
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	3188	1187	10.1	12834	2045	28.2	12933	808	13.0	1048	76	7.2	16838	1812	18.6
<i>Diaptomus</i> C ₆	1333	373	4.2	2473	187	5.4	3773	242	3.8	1200	101	8.2	4912	691	5.4
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	0	0	0.0	34	34	0.1	25	5	0.0	11	10	0.1	40	40	0.0
<i>Eurytemora</i> C ₁ -C ₅	1004	593	3.2	249	31	0.5	215	12	0.2	1659	675	11.4	1020	298	1.1
<i>Eurytemora</i> C ₆	71	47	0.2	140	35	0.3	101	36	0.1	212	64	1.5	969	173	1.1
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	14	14	0.0	54	27	0.1	78	34	0.1	2	3	0.0	50	36	0.1
Haracticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans															
<i>Boeckma</i>	17234	7504	54.7	11789	701	26.0	48205	6025	48.6	5493	1135	37.7	22503	1531	24.8
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	0	0	0.0	4	4	0.0	0	0	0.0	2	2	0.0	40	40	0.0
<i>Daphnia</i>	131	107	0.4	532	48	1.2	870	207	0.9	34	9	0.2	1368	324	1.5
<i>Diaphanosoma</i>	21	16	0.1	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Eubosmina</i>	10	10	0.0	47	30	0.1	190	58	0.2	16	16	0.1	40	27	0.0
<i>Holopedium</i>	3	3	0.0	98	38	0.2	29	1	0.0	4	3	0.0	50	50	0.1
<i>Leptodora</i>	3	3	0.0	17	17	0.0	25	5	0.0	3	3	0.0	0	0	0.0
<i>Polyphemus</i>	320	-	1.0	69	69	0.1	162	38	0.2	513	-	3.5	0	0	0.0
Rotifers															
<i>Asplanchna</i>	424	131	1.3	832	204	1.8	798	196	0.8	1229	340	8.4	914	268	1.0
Total	31476	12709		45473	4443		99251	8242		14553	2212		90688	5249	
Dry wt (mg/m ³)	55	6		170	103		201	3		37	6		387	54	
Dry wt (µg/individual)	1.2	0.3		3.4	1.6		2.0	0.2		2.6	0.8		4.2	0.4	

TABLE 6. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 7 stations on August 23, 1973.

Species	DC-2			DC-5			DC-6		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	254.54	4293	30.5	10746	3225	19.7	3549	277	8.2
Cyclopoid copepods	30422	2132	36.5	14890	2444	27.4	10013	100	23.2
<i>Cyclops</i> C ₁ -C ₅	1665	318	2.0	4094	595	7.5	1895	159	4.4
<i>Cyclops bicuspidatus thomasi</i>	15	15	0.0	6	6	0.0	0	0	0.0
<i>Cyclops vernalis</i>	3244	711	3.9	682	255	1.2	1613	76	3.7
<i>Tropocyclops prasinus mexicanus</i>									
Calanoid copepods	9987	742	12.0	13502	2589	24.8	16661	305	38.5
<i>Diaptomus</i> C ₁ -C ₅	634	175	0.8	2647	510	4.9	1870	189	4.3
<i>Diaptomus ashlandi</i>	275	13	0.3	213	39	0.4	778	78	1.8
<i>Diaptomus minutus</i>	65	12	0.1	287	53	0.5	330	81	0.8
<i>Diaptomus oregonensis</i>	0	0	0.0	0	0	0.0	37	10	0.1
<i>Diaptomus siatis</i>	83	42	0.1	13	13	0.0	0	0	0.0
<i>Epischura</i> C ₁ -C ₅	17	9	0.0	38	1	0.1	0	0	0.0
<i>Epischura lacustris</i>	187	36	0.2	154	61	0.3	0	0	0.0
<i>Eurytemora</i> C ₁ -C ₅	15	15	0.0	102	19	0.2	0	0	0.0
<i>Eurytemora affinis</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	152	12	0.3	373	34	0.9
<i>Limnocalanus macrurus</i>									
Harpacticoid copepods	0	0	0.0	0	0	0.0	0	0	0.0
<i>Canthocamptus</i> sp									
Cladocerans	402	132	0.5	3739	616	6.9	1397	84	3.2
<i>Boeckma longirostris</i>	9	9	0.0	0	0	0.0	10	10	0.0
<i>Ceriodaphnia quadrangula</i>	43	25	0.0	6	6	0.0	38	26	0.1
<i>Chydorus sphaericus</i>	1293	502	1.5	393	59	0.7	385	64	0.9
<i>Daphnia galeata mendotae</i>	9007	744	10.8	2572	255	4.7	3751	312	8.7
<i>Daphnia retrocurva</i>	109	37	0.1	0	0	0.0	54	16	0.1
<i>Diaphanosoma leuchtenbergianum</i>	92	23	0.1	70	5	0.1	248	66	0.6
<i>Eubosmina coregoni</i>	118	5	0.1	19	10	0.0	82	28	0.2
<i>Holopedium gibberum</i>	211	102	0.2	31	11	0.1	27	1	0.1
<i>Leptodora kindtii</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Polyphemus pediculus</i>									
Rotifers	57	57	0.1	37	21	0.1	119	20	0.3
<i>Asplanchna priodonta</i>									
Total	-83043	8802		54406	10423		43237	949	
Dry wt (mg/m ³)	118	13		122	18		98	8	
Dry wt (µg/individual)	1.4	0.0		2.3	0.1		2.3	0.2	

TABLE 6 continued. August 23, 1973.

Genus	DC-3			DC-4			NDC-.5-2			SDC-.5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	13147	3071	13.9	18268	4147	16.5	13055	2979	27.1	20513	1724	27.5
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	34913	5516	36.9	34644	6079	31.4	19668	4331	40.8	26511	3696	35.5
<i>Cyclops</i> C ₆	7708	824	8.1	7977	2307	7.2	1808	331	3.7	3119	557	4.2
<i>Tropocyclops</i>	1367	389	1.4	1663	426	1.5	741	262	1.5	2614	286	3.5
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	17807	2401	18.8	27907	5717	25.3	3206	780	6.6	6663	1120	8.9
<i>Diaptomus</i> C ₆	5358	1255	5.7	4556	329	4.1	371	229	0.8	674	39	0.9
<i>Epischura</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₆	19	10	0.0	140	73	0.1	0	0	0.0	12	12	0.0
<i>Eurytemora</i> C ₁ -C ₅	109	73	0.1	216	159	0.2	486	131	1.0	96	48	0.1
<i>Eurytemora</i> C ₆	66	24	0.1	152	99	0.1	27	27	0.1	12	12	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Boeima</i>	2974	1156	3.1	3471	726	3.1	1316	919	2.7	827	267	1.1
<i>Ceriodaphnia</i>	10	10	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	10	10	0.0	10	9	0.0	0	0	0.0	12	6	0.0
<i>Daphnia</i>	10304	2373	10.9	10668	1975	9.7	7058	2576	14.6	12940	1295	17.3
<i>Diaphanosoma</i>	15	9	0.0	241	140	0.2	45	32	0.1	33	10	0.0
<i>Eubosmina</i>	486	122	0.5	220	132	0.2	9	9	0.0	377	53	0.5
<i>Holopedium</i>	103	61	0.1	135	38	0.1	113	80	0.2	85	38	0.1
<i>Leptodora</i>	149	74	0.2	106	64	0.1	208	115	0.4	188	44	0.2
<i>Polyphemus</i>	5	5	0.0	0	0	0.0	62	32	0.1	17	17	0.0
Rotifers												
<i>Asplanchna</i>	5	5	0.0	0	0	0.0	36	36	0.1	12	6	0.0
Total	94560	15968		110389	19947		48204	12305		74704	6631	
Dry wt (mg/m ³)	222	47		261	23		200	125		127	20	
Dry wt (µg/individual)	2.3	0.2		2.4	0.3		4.0	1.0		1.7	0.3	

TABLE 7. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 7 stations on September 20, 1973.

Species	DC-2			DC-5			DC-6		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	2081	267	3.1	508	108	1.2	375	139	1.5
Cyclopoid copepods									
<i>Cyclops</i> C ₁ -C ₅	6731	1027	9.9	14698	312	35.2	7117	733	29.0
<i>Cyclops bicuspidatus thomasi</i>	150	59	0.2	1607	128	3.8	1502	84	6.1
<i>Cyclops vernalis</i>	14	14	0.0	0	0	0.0	11	12	0.0
<i>Tropocyclops prasinus mexicanus</i>	138	76	0.2	647	57	1.5	411	47	1.7
Calanoid copepods									
<i>Diaptomus</i> C ₁ -C ₅	1355	312	2.0	6062	418	14.5	6636	337	27.1
<i>Diaptomus ashlandi</i>	83	32	0.1	428	51	1.0	634	51	2.6
<i>Diaptomus minutus</i>	220	64	0.3	66	3	0.2	59	13	0.2
<i>Diaptomus oregonensis</i>	14	7	0.0	200	44	0.5	99	25	0.4
<i>Diaptomus stali</i>	0	0	0.0	29	29	0.1	146	48	0.6
<i>Epischura</i> C ₁ -C ₅	165	41	0.2	70	32	0.2	36	20	0.1
<i>Epischura lacustris</i>	0	0	0.0	62	28	0.1	32	3	0.1
<i>Eurytemora</i> C ₁ -C ₅	633	90	0.9	168	47	0.4	104	27	0.4
<i>Eurytemora affinis</i>	51	7	0.1	41	6	0.1	6	6	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus macrurus</i>	0	0	0.0	8	4	0.0	91	17	0.4
Harpacticoid copepods									
<i>Canthocamptus</i> sp	0	0	0.0	0	0	0.0	0	0	0.0
Gladocerans									
<i>Boemina longirostris</i>	47035	8549	69.2	5655	464	13.6	1319	200	5.4
<i>Ceriodaphnia quadrangula</i>	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus sphaericus</i>	32	32	0.0	45	12	0.1	11	3	0.0
<i>Daphnia galeata mendotae</i>	269	154	0.4	477	42	1.1	381	23	1.6
<i>Daphnia retrocurva</i>	2575	961	3.8	8166	944	19.6	4522	292	18.5
<i>Diaphanosoma leuchtenbergianum</i>	364	100	0.5	274	109	0.7	80	11	0.3
<i>Eubosmina coregoni</i>	369	132	0.5	329	50	0.8	167	44	0.7
<i>Heptodonta gibberum</i>	80	30	0.1	11	6	0.0	22	8	0.1
<i>Leptodonta knutti</i>	85	54	0.1	114	43	0.3	22	7	0.1
<i>Polyphemus pediculus</i>	146	12	0.2	27	13	0.1	11	2	0.0
Rotifers									
<i>Asplanchna priodonta</i>	5338	719	7.8	1961	349	4.7	689	54	2.8
Total	67994	11964		4712	1138		24499	1590	
Dry wt (mg/m ³)				124	9		84	6	
Dry wt (µg/individual)				3.0	0.1		3.4	0.4	

TABLE 7 continued. September 20, 1973.

Genus	DC-3			DC-4			NDC-5-2			SDC-5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	1396	64	2.1	1665	178	2.4	1578	443	3.8	1958	36	4.7
Cyclopoid copepods	18399	1213	27.5	20037	238	28.5	6583	466	15.9	5081	747	12.3
<i>Cyclops</i> C ₁ -C ₅	2112	621	3.2	1869	308	2.6	746	110	1.8	429	125	1.0
<i>Cyclops</i> C ₆	681	49	1.0	895	262	1.3	73	50	0.2	53	36	0.1
<i>Tropocyclops</i>												
Calanoid copepods	7169	738	10.7	7990	1273	11.3	1978	274	4.8	1485	122	3.6
<i>Diaptomus</i> C ₁ -C ₅	1087	79	1.6	1047	357	1.5	219	104	0.5	245	68	0.6
<i>Diaptomus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Epischura</i> C ₁ -C ₅	156	58	0.2	116	44	0.2	51	11	0.1	28	16	0.1
<i>Epischura</i> C ₆	179	64	0.3	117	46	0.2	103	28	0.2	363	171	0.9
<i>Eurytemora</i> C ₁ -C ₅	58	12	0.1	49	18	0.1	171	87	0.4	63	48	0.1
<i>Eurytemora</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Canthocamptus</i>												
Cladocerans	11597	3209	17.4	10734	1614	15.2	20788	345	50.2	25171	666	60.9
<i>Bosmina</i>	5	5	0.0	14	14	0.0	0	0	0.0	0	0	0.0
<i>Ceriodaphnia</i>	169	62	0.2	210	134	0.3	436	51	1.0	172	65	0.4
<i>Chydorus</i>	15490	1241	23.2	18226	4211	25.9	2413	508	5.8	1590	219	3.8
<i>Daphnia</i>	825	102	1.2	850	81	1.2	284	155	0.7	198	42	0.5
<i>Diaphanosoma</i>	942	348	1.4	895	226	1.3	349	25	0.8	335	165	0.8
<i>Eubosmina</i>	124	38	0.2	48	12	0.1	87	19	0.2	36	18	0.1
<i>Holopedium</i>	85	43	0.1	17	10	0.0	143	20	0.3	224	107	0.5
<i>Leptodora</i>	62	19	0.1	52	26	0.1	103	35	0.2	28	28	0.1
<i>Polyphemus</i>												
Rotifers	6264	899	9.4	5576	801	7.9	5163	511	12.5	3796	561	9.2
<i>Asplanchna</i>												
Total	66797	6815		70412	11252		41365	2139		41310	1808	
Dry wt (mg/m ³)	275	30		290	-					269	50	
Dry wt (µg/individual)	4.1	0.4		3.2	-					6.4	0.9	

TABLE 8. Mean abundances, standard deviations of the mean, percentage compositions, and dry weights for zooplankton collected at 27 stations on October 23, 1973.

Species	DC-2			DC-5			DC-6			NDC-7-5			SDC-7-5		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii															
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	8690	767	38.1	12364	563	41.7	14579	863	45.6	12364	492	38.6	12335	1153	35.8
<i>Cyclops bicuspidatus thomasi</i>	529	95	2.3	718	67	2.4	826	64	2.6	794	33	2.5	759	71	2.2
<i>Cyclops vernalis</i>	6	6	0.0	3	3	0.0	0	0	0.0	10	9	0.0	0	0	0.0
<i>Tropocyclops prasinus mexicanus</i>	775	77	3.4	560	90	1.9	789	55	2.8	589	144	1.8	981	313	2.8
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	4648	49	20.4	9509	1037	32.0	10040	283	31.4	9068	405	28.3	11081	1456	32.2
<i>Diaptomus ashlandi</i>	96	21	0.4	250	38	0.8	387	8	1.2	271	11	0.8	506	122	1.5
<i>Diaptomus minutus</i>	16	5	0.1	30	11	0.1	44	6	0.1	94	20	0.3	132	11	0.4
<i>Diaptomus oregonensis</i>	150	27	0.7	201	50	0.7	526	35	1.6	225	1	0.7	192	10	0.5
<i>Diaptomus stoealis</i>	5	3	0.0	9	5	0.0	161	42	0.5	29	9	0.1	20	20	0.0
<i>Epischura</i> C ₁ -C ₅	61	20	0.3	85	30	0.3	48	3	0.2	140	29	0.4	233	30	0.7
<i>Epischura lacustris</i>	35	2	0.1	168	38	0.6	55	39	0.2	261	54	0.8	71	50	0.2
<i>Eurytemora</i> C ₁ -C ₅	66	17	0.3	43	17	0.1	22	6	0.1	47	28	0.1	71	10	0.2
<i>Eurytemora affinis</i>	5	3	0.0	37	11	0.1	22	6	0.1	56	0	0.2	30	10	0.1
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus macrurus</i>	0	0	0.0	0	0	0.0	113	39	0.4	0	0	0.0	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i> sp	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans															
<i>Bosmina longirostris</i>	2280	66	10.0	925	18	3.1	304	51	1.0	1138	216	3.5	809	0	2.3
<i>Ceriodaphnia quadrangula</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus sphaericus</i>	19	10	0.1	0	0	0.0	11	6	0.0	19	0	0.0	0	0	0.0
<i>Daphnia galeata mendotae</i>	748	114	3.3	1186	48	4.0	727	37	2.3	1485	37	4.6	2073	617	6.0
<i>Daphnia retrocurva</i>	1547	272	6.8	1199	55	4.0	1056	59	3.3	1242	36	3.9	1527	515	4.4
<i>Diaphanosoma leuckertbergianum</i>	54	18	0.2	49	8	0.2	51	25	0.2	103	8	0.3	81	61	0.2
<i>Eubosmina coregoni</i>	1904	141	8.3	1107	96	3.7	1060	104	3.3	2623	104	8.2	1790	313	5.2
<i>Hoopedium gibberum</i>	60	14	0.3	73	21	0.2	15	3	0.0	94	20	0.3	344	61	1.0
<i>Leptodora kindtii</i>	11	6	0.0	9	9	0.0	4	3	0.0	29	9	0.1	31	30	0.1
<i>Leptodora pedicularis</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	10	10	0.0
Rotifers															
<i>Asplanchna priodonta</i>	573	100	2.5	627	102	2.1	351	59	1.1	710	23	2.2	739	131	2.1
Total	22791	648		29680	1910		31931	1401		32038	668		34426	5047	
Dry wt (mg/m³)	91	11		88	2		107	12		103	4		100	15	
Dry wt (µg/individual)	4.1	0.5		3.0	0.1		3.3	0.2		3.2	0.0		2.9	0.0	

TABLE 8 continued. October 23, 1973.

Genus	DC-3			DC-4			NDC-5-2			SDC-5-2		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	941	91	3.2	470	79	2.0	603	57	3.0	540	43	1.7
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	8973	1768	30.3	7818	292	33.1	5768	647	28.4	7134	79	22.6
<i>Cyclops</i> C ₆	1409	234	4.8	714	153	3.0	625	169	3.1	731	58	2.3
<i>Tropocyclops</i>	968	231	3.2	547	63	2.3	1081	237	5.3	1073	124	3.4
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	4432	686	15.0	6621	546	28.1	2688	487	13.2	2123	136	6.7
<i>Diaptomus</i> C ₆	452	247	1.5	277	40	1.2	111	40	0.6	125	18	0.4
<i>Eurytemora</i> C ₁ -C ₅	176	145	0.6	112	57	0.5	35	15	0.2	24	16	0.1
<i>Eurytemora</i> C ₆	43	5	0.1	282	39	1.2	64	14	0.3	79	14	0.2
<i>Eurytemora</i> C ₁ -C ₅	243	87	0.8	68	29	0.3	120	19	0.6	100	36	0.3
<i>Eurytemora</i> C ₆	52	1	0.2	57	13	0.2	13	7	0.1	10	10	0.0
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans												
<i>Boeckingia</i>	1900	418	6.4	1646	141	7.0	2979	401	14.7	8947	682	28.3
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	17	12	0.1	4	3	0.0	16	10	0.1	23	12	0.1
<i>Daphnia</i>	4433	1092	15.0	2902	384	12.3	2230	434	11.0	4823	341	15.2
<i>Diaphanosoma</i>	71	16	0.2	41	23	0.2	48	24	0.4	135	49	0.4
<i>Eubosmina</i>	4921	648	16.6	1555	257	6.6	3472	451	17.1	5166	514	16.3
<i>Holopedium</i>	145	31	0.5	55	8	0.2	115	63	0.6	176	10	0.5
<i>Leptodora</i>	77	2	0.3	5	5	0.0	103	34	0.5	90	19	0.3
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers												
<i>Asplanchna</i>	361	29	1.2	398	36	1.7	277	42	1.4	325	54	1.0
Total	29617	4763		23594	1238		20323	2607		31622	1643	
Dry wt (mg/m ³)	192	-		104	17		119	21		174	30	
Dry wt (µg/individual)	6.2	-		4.5	0.4		6.8	1.8		5.5	1.1	

TABLE 8 continued. October 23, 1973.

Genus	NDC-1-1			SDC-1-1			NDC-2-1			NDC-2-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	833	66	3.0	1049	244	3.2	668	125	2.1	462	38	1.7
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	2266	645	8.3	6197	2252	19.2	3820	224	12.0	10234	345	36.9
<i>Cyclops</i> C ₆	209	81	0.8	1035	100	3.2	624	64	2.0	943	159	3.4
<i>Tropocyclops</i>	427	138	1.6	1812	183	5.6	1757	349	5.5	778	164	2.8
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	1767	435	6.4	3012	527	9.3	3072	58	9.7	6773	507	24.4
<i>Diaptomus</i> C ₆	113	12	0.4	137	30	0.4	194	47	0.6	234	112	0.8
<i>Epischura</i> C ₁ -C ₅	39	18	0.1	318	150	1.0	162	68	0.5	171	91	0.6
<i>Epischura</i> C ₆	96	49	0.3	49	9	0.1	145	59	0.4	207	50	0.7
<i>Eurytemora</i> C ₁ -C ₅	425	102	1.5	183	68	0.6	158	42	0.5	74	27	0.3
<i>Eurytemora</i> C ₆	3	3	0.0	22	15	0.1	23	23	0.1	28	6	0.1
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	7	7	0.0
Harpacticoid copepods												
<i>Haracticoid copepods</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans												
<i>Bosmina</i>	11016	824	40.1	5188	583	16.1	8351	1144	26.3	2611	313	9.4
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	0	0	0.0	17	10	0.0	3	3	0.0	9	6	0.0
<i>Daphnia</i>	1815	757	6.6	3649	691	11.3	3023	263	9.5	2789	124	10.1
<i>Diaphanosoma</i>	38	21	0.1	44	20	0.1	82	48	0.2	104	50	0.4
<i>Eubosmina</i>	7659	1704	27.9	8841	4	27.4	9233	1475	29.1	1751	275	6.3
<i>Holopedium</i>	305	24	1.1	99	18	0.3	190	33	0.6	132	47	0.5
<i>Leptodora</i>	141	4	0.5	72	20	0.2	68	12	0.2	41	5	0.1
<i>Polyphehus</i>	9	9	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Rotifers												
<i>Asplanchna</i>	188	93	0.7	578	76	1.8	167	4	0.5	374	29	1.3
Total	27462	4084		36905	4250		31742	1565		27720	1341	
Dry wt (mg/m ³)	249	-					208	19		117	20	
Dry wt (µg/individual)	9.6	-					6.5	1.0		4.0	0.4	

TABLE 8 continued. October 23, 1973.

Genus	NDC-4-1			NDC-4-3			NDC-4-4			NDC-7-1			NDC-7-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	1098	166	3.3												
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	5095	573	15.4	15160	1154	40.2	14462	2726	34.1	4699	58	19.6	7457	636	27.4
<i>Cyclops</i> C ₆	627	212	1.9	1499	674	4.0	1800	540	4.2	801	151	3.3	2353	685	8.6
<i>Tropocyclops</i>	1008	164	3.0	709	58	1.9	594	272	1.4	1339	77	5.6	1105	50	4.1
Galanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	2037	221	6.1	8543	1176	22.6	14413	3324	34.0	2562	232	10.7	2730	326	10.0
<i>Diaptomus</i> C ₆	224	104	0.7	740	341	2.0	1386	539	3.3	132	14	0.5	269	72	1.0
<i>Epischura</i> C ₁ -C ₅	42	21	0.1	48	35	0.1	6	6	0.0	473	397	2.0	59	6	0.2
<i>Epischura</i> C ₆	57	27	0.2	220	48	0.6	262	102	0.6	26	13	0.1	139	47	0.5
<i>Eurytemora</i> C ₁ -C ₅	501	64	1.5	87	9	0.2	36	16	0.1	327	23	1.4	88	14	0.3
<i>Eurytemora</i> C ₆	82	23	0.2	92	65	0.2	17	8	0.0	85	7	0.3	50	28	0.2
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	443	100	1.0	0	0	0.0	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocera															
<i>Bosmina</i>	8365	2324	25.3	2334	277	6.2	790	364	1.9	1632	210	6.8	1697	264	6.2
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	7	0	0.2	6	3	0.0	15	13	0.0	3	3	0.0	3	3	0.0
<i>Daphnia</i>	2873	346	8.7	4217	662	11.2	5729	1805	13.5	5334	200	22.3	5285	144	19.4
<i>Diaphanosoma</i>	58	5	0.2	23	16	0.1	15	8	0.0	60	8	0.2	89	12	0.3
<i>Eubosmina</i>	10295	2428	31.1	2536	361	6.7	1605	677	3.8	5460	910	22.8	4984	791	18.3
<i>Holopedium</i>	435	66	1.3	120	21	0.3	26	21	0.1	133	23	0.5	101	25	0.4
<i>Leptodora</i>	112	29	0.3	27	2	0.1	52	17	0.1	93	22	0.4	80	12	0.3
<i>Polyphemus</i>	8	8	0.0	4	4	0.0	2	2	0.0	3	3	0.0	0	0	0.0
Rotifers															
<i>Asplanchna</i>	188	33	0.6	682	23	1.8	215	87	0.5	314	40	1.3	194	70	0.7
Total	33111	6216		37706	4585		42436	10378		23947	958		27194	1737	
Dry wt (mg/m ³)	233	-		114	22		195	41		154	17		161	6	
Dry wt (µg/individual)	5.1	-		3.0	0.6		4.8	0.3		6.3	0.7		5.8	0.2	

TABLE 8 continued. October 23, 1973.

Genus	SDC-1-1			SDC-1-2			SDC-2-1			SDC-2-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	401	47	2.3	387	76	1.6	793	72	3.3	533	199	1.8
Cyclopoid copepods												
<i>Cyclops</i> C ₁ -C ₅	2574	407	14.5	7733	1660	32.8	3670	924	15.4	9999	1525	33.6
<i>Cyclops</i> C ₆	658	166	3.7	804	157	3.4	1186	91	5.0	725	75	2.4
<i>Tropocyclops</i>	227	58	1.3	577	300	2.4	301	93	1.3	501	53	1.7
Calanoid copepods												
<i>Diaptomus</i> C ₁ -C ₅	2051	262	11.6	3803	905	16.1	1591	206	6.7	7043	1177	23.7
<i>Diaptomus</i> C ₆	144	60	0.8	164	36	0.7	129	20	0.5	322	81	1.1
<i>Epischura</i> C ₁ -C ₅	21	18	0.1	6	3	0.0	216	204	0.9	22	11	0.1
<i>Epischura</i> C ₆	38	9	0.2	110	56	0.5	47	5	0.2	201	32	0.7
<i>Eurytemora</i> C ₁ -C ₅	106	61	0.6	82	27	0.3	718	174	3.0	72	9	0.2
<i>Eurytemora</i> C ₆	5	5	0.0	13	9	0.0	37	13	0.1	23	16	0.1
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods												
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans												
<i>Bosmina</i>	5456	861	30.8	3909	1000	16.6	9403	3360	39.5	3975	510	13.4
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	8	6	0.0	3	3	0.0	9	9	0.0	39	24	0.1
<i>Daphnia</i>	1096	155	6.2	2322	666	9.8	1636	591	6.9	2742	894	9.2
<i>Diaphanosoma</i>	23	11	0.1	80	48	0.3	53	18	0.2	46	10	0.1
<i>Eubosmina</i>	4581	1156	25.8	2898	970	12.3	3288	674	13.8	2867	81	9.6
<i>Holopedium</i>	173	29	1.0	102	9	0.4	578	177	2.4	81	15	0.3
<i>Leptodora</i>	119	8	0.7	20	11	0.1	97	48	0.4	47	25	0.1
<i>Polyphemus</i>	0	0	0.0	0	0	0.0	0	0	0.0	7	8	0.0
Rotifers												
<i>Asplanchna</i>	49	13	0.3	346	51	1.5	69	37	0.3	461	47	1.5
Total	17729	1770		23564	5540		23822	3009		29708	4344	
Dry wt (mg/m ³)	129	21		141	15		116	22		160	41	
Dry wt (μg/individual)	7.1	1.0		6.3	1.7		5.0	1.1		5.2	0.6	

TABLE 8 continued. October 23, 1973.

Genus	SDC-4-1			SDC-4-3			SDC-4-4			SDC-7-1			SDC-7-3		
	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%	#/m ³	Sx	%
Copepod nauplii	491	38	2.3	456	53	1.4	1221	445	2.4	232	35	2.5	503	237	1.9
Cyclopoid copepods															
<i>Cyclops</i> C ₁ -C ₅	3793	434	18.2	12450	2301	38.3	17823	7657	35.7	2794	1188	30.8	10771	833	40.7
<i>Cyclops</i> C ₆	973	180	4.7	1055	84	3.2	2992	900	6.0	364	64	4.0	1035	194	3.9
<i>Tropocyclops</i>	402	155	1.9	870	156	2.7	777	244	1.5	324	164	3.6	866	96	3.3
Calanoid copepods															
<i>Diaptomus</i> C ₁ -C ₅	2016	293	9.6	7319	1962	22.5	16028	7156	32.1	370	175	4.0	6275	725	23.7
<i>Diaptomus</i> C ₆	94	21	0.4	539	324	1.6	2005	1533	4.0	43	33	0.5	238	10	0.9
<i>Epischura</i> C ₁ -C ₅	153	54	0.7	220	153	0.7	303	292	0.6	38	31	0.4	183	124	0.7
<i>Epischura</i> C ₆	113	62	0.5	451	152	1.4	231	141	0.5	116	111	1.3	89	9	0.3
<i>Eurytemora</i> C ₁ -C ₅	597	17	2.9	90	45	0.3	45	12	0.1	226	118	2.5	63	12	0.2
<i>Eurytemora</i> C ₆	5	5	0.0	26	12	0.1	36	14	0.1	0	0	0.0	16	2	0.1
<i>Limnocalanus</i> C ₁ -C ₅	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Limnocalanus</i> C ₆	0	0	0.0	0	0	0.0	14	14	0.0	0	0	0.0	0	0	0.0
Harpacticoid copepods															
<i>Canthocamptus</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
Cladocerans															
<i>Bosmina</i>	3251	271	15.6	2794	821	8.6	1502	685	3.0	2221	386	24.5	1172	57	4.4
<i>Ceriodaphnia</i>	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0	0	0	0.0
<i>Chydorus</i>	2	2	0.0	18	10	0.0	5	3	0.0	3	3	0.0	28	8	0.1
<i>Daphnia</i>	2765	343	13.2	2863	1173	8.8	4567	2025	9.1	539	361	5.9	2191	326	8.3
<i>Diaphanosoma</i>	21	16	0.1	28	10	0.1	23	12	0.1	30	16	0.3	96	31	0.4
<i>Eubosmina</i>	5762	315	27.6	2616	578	8.0	2085	748	4.2	1561	217	17.2	2535	439	9.6
<i>Holopedium</i>	245	25	1.2	115	8	0.3	58	29	0.1	166	27	1.8	21	14	0.1
<i>Leptodora</i>	55	16	0.3	45	23	0.1	47	32	0.1	22	6	0.2	36	23	0.1
<i>Polypheuma</i>	0	0	0.0	0	0	0.0	4	4	0.0	2	2	0.0	0	0	0.0
Rotifers															
<i>Asplanchna</i>	131	28	0.6	526	196	1.6	398	150	0.8	18	16	0.2	314	51	1.2
Total	20870	1907		32482	7639		49864	20843		9071	2270		26434	2867	
Dry wt (mg/m ³)	129	28		123	53		179	85		76	17		120	20	
Dry wt (µg/individual)	6.2	1.1		4.1	0.5		3.6	0.2		8.5	1.0		4.3	0.0	

methods were uncovered. In 1972, numbers of *Cyclops* adults were overestimated at the expense of immature cyclopoids for most of the samples counted to genus. In 1970 and 1971, numbers of *Polyphemus* may have been overestimated, while abundance of *Eurytemora* is likely to have been underestimated.

Our field study methods were discussed by Roth (1973), but a few additional comments are worth making. (1) Sampling precision was generally greater at deeper stations. Greater accuracy in measuring the volume of water filtered is one likely explanation (flowmeter readings are more consistent); another is the greater amount of averaging expected from a longer haul. It may also be supposed that inshore waters are less homogeneous. (2) Sampling precision was greater in April than in the summer or fall months. This is shown in Figure 1 where the coefficients of variation (standard deviations expressed as percentages of the means) are plotted against species abundance. For the most abundant taxa, standard deviations averaged between 15% and 20% of the mean in the spring, between 20% and 30% in July and October. (3) Figure 1 also illustrates the decreased accuracy with which populations of the rarer taxa are measured on months when total standing crops are larger. This is because smaller subsamples must be made. The higher standard deviations result from the small number of individuals in each subsample, i.e., in this case subsampling is the largest source of error. (4) On the other hand, for abundant taxa, variation between subsamples of the same replicate was less than variation between replicates. The standard deviation between subsamples falls to 10% or lower for the most common organisms. (5) Variation between stations in the same depth zone is greater than variation between replicates taken at the same station. This suggests that we are detecting large-scale patchiness, whereas the sampling method (large net, long hauls) minimizes the effects of small-scale patchiness.

(6) Differences between months and between years are generally much greater than differences between stations sampled on the same date.

FIELD STUDY RESULTS

The year 1973 was warmer than 1972; a mild winter was followed by an early spring, comparatively higher summer temperatures, and an extended autumn. Phytoplankton standing crops were higher than in 1972 in all but one month (October) and tended to remain between 1000 and 2000 cells/ml throughout the sampling season (see Ayers and Kopczynska 1974). This contrasts with counts of less than 500/ml obtained in July, August, and September of 1972. Zooplankton were twice as abundant in the spring months of April, May and June, with several species appearing earlier than in 1972. Unlike the previous year, the 1973 zooplankton reached July and August maxima that did not exceed 100,000/m³. Cladocerans, which make up the bulk of these late-summer peaks, were less abundant, while the more perennial copepod species appeared in similar and sometimes greater numbers.

The zooplankton making up the fauna are listed in Table 9. Six of the rare taxa on this list -- *Eucyclops speratus*, *Bryocamptus* sp., *Diaphanosoma brachyurum*, *Latona setifera*, *Scapholeberis kingi*, and *Sida crystallina* -- were noted for the first time in 1973; but the 21 species having abundances greater than 10/m³ are the same as those comprising the 1971 and 1972 faunas. The broader patterns of succession described for southern Lake Michigan by Johnson (1972) and by Roth and Stewart (1973) were also repeated. Two interesting deviations were the rarity of *Ceriodaphnia quadrangulatis*, a species whose abundance exceeded 400/m³ in September 1971 and August 1972, and the failure of *Holopedium gibberum* to produce a distinct fall bloom as in 1971 and 1972.

TABLE 9. Species of zooplankton crustacea collected within the Cook survey area in 1973 and their maximum monthly abundance.

	#/m ³
Cyclopoid copepods	
<i>Cyclops bicuspidatus thomasi</i> S. A. Forbes	5,000
<i>Cyclops vernalis</i> Fischer	50
<i>Eucyclops agilis</i> (Koch)	<1
<i>Eucyclops speratus</i> (Lilljeborg)	<1
<i>Mesocyclops edax</i> (S. A. Forbes)	<1
<i>Paracyclops fimbriatus poppei</i> (Rehberg)	<1
<i>Therapsyclops prasinus mexicanus</i> Kiefer	1,700
Calanoid copepods	
<i>Diaptomus ashlandi</i> Marsh	3,400
<i>Diaptomus minutus</i> Lilljeborg	1,600
<i>Diaptomus oregonensis</i> Lilljeborg	530
<i>Diaptomus sicilis</i> S. A. Forbes	160
<i>Epischura lacustris</i> S. A. Forbes	180
<i>Eurytemora affinis</i> (Poppe)	250
<i>Limnocalanus macrurus</i> Sars	270
Harpacticoid copepods	
<i>Bryocamptus</i> sp.	<1
<i>Canthocamptus</i> sp.	40
Cladocera	
<i>Alona</i> sp.	<1
<i>Alona affinis</i> (Leydig)	2
<i>Bosmina longirostris</i> (O. F. Müller)	29,000
<i>Ceriodaphnia quadrangula</i> (O. F. Müller)	10
<i>Glydurus sphaericus</i> (O. F. Müller)	300
<i>Daphnia galeata mendotae</i> Birge	1,300
<i>Daphnia longiremis</i> Sars	4
<i>Daphnia retrocurva</i> S. A. Forbes	9,000
<i>Diaphanosoma brachyurum</i> (Liéven)	<1
<i>Diaphanosoma leuchtenbergianum</i> Fischer	580
<i>Eubosmina coregoni</i> (Baird)	6,000
<i>Euryoercus lamellatus</i> (O. F. Müller)	2
<i>Holopedium gibberum</i> Zaddach	600
<i>Ilyocryptus sordidus</i> (Liéven)	<1
<i>Latona setifera</i> (O. F. Müller)	<1
<i>Leptodora kindtii</i> (Focke)	200

TABLE 9 continued.

	#/m ³
<i>Leydigia quadrangularis</i> (Leydig)	<1
<i>Macrothrix laticornis</i> (Jurine)	<1
<i>Pleuroxus denticulatus</i> Birge	<1
<i>Polyphemus pediculus</i> (Linné)	380
<i>Scapholeberis kingi</i> Sars	<1
<i>Sida crystallina</i> (O. F. Müller)	<1
Ostracoda	<1
Amphipoda	
<i>Pontoporeia affinis</i> Lindstrom	<1
Mysidacea	
<i>Mysis relicta</i> Lovén	<1

Figure 3 compares total zooplankton numbers in 1973 with numbers in 1971 and 1972, the other years in which a #10 net was used. For the purpose of discussion, we have divided the survey region into three zones; each point on this and similar graphs appearing with the natural history section represents the mean of all stations within each zone. The compositional differences between samples collected at shallow and deep stations makes a division useful, although the instability of plankton populations makes it necessarily arbitrary. The 3 stations deeper than 30 m will be most representative of offshore conditions. In this zone hypolimnetic organisms such as *Limnocalanus* can usually be found throughout the year. Cladoceran populations are usually lower here, while copepods are as abundant or more abundant than inshore. The 10 stations inside the 10-m contour have been separated into what, for want of a better name, is called the littoral zone. This coincides with the "beach zone" used by the

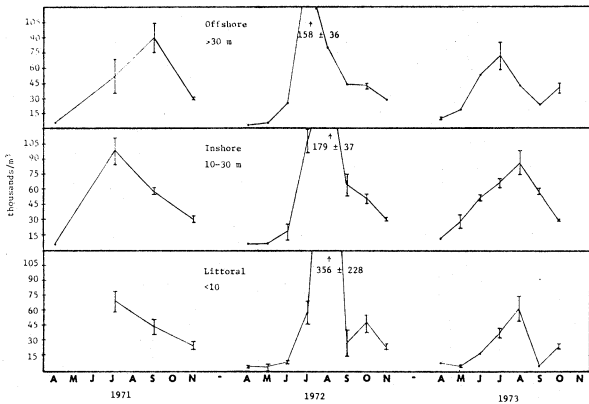


FIGURE 3. Seasonal distribution of total zooplankton abundance. Plotted are means for all stations located within each of three depth zones.

Great Lakes Fishery Laboratory (1970) for their estimates of the magnitude of thermal input into Lake Michigan. Vertically migrating copepods are usually rare in this zone during the warm months. Cladoceran populations are nearly identical with those at stations between 10 m and 30 m. The remaining region, between 10 and 30 m, will be called the inshore zone in this report.

Figures 4 and 5 compare dry weights per volume and per animal with those weights obtained in 1972. In this case, because of the smaller amount of data from 1972, we have charted measurements from 3 representative stations, DC-2, DC-5, and DC-6. At 13, 25, and 40 m, these stations lie at the shallow and deep extremes of the inshore zone and in the offshore zone. A pattern of low spring biomasses followed by summer and fall biomasses of 90-120 mg/m³ was repeated, as was the tendency for animals to be smaller in June, July, and August. However, as with total numbers, large July and August peaks did not occur. Mean weights per animal were distinctly different in April and May. In 1972, weights of 9-10 micrograms were measured at the offshore station, whereas in 1973 earlier warming was accompanied by an earlier appearance of large numbers of nauplii and a resultant decrease in the average weight per individual.

THE MAJOR SURVEY OF 25 APRIL 1973

On 24 April, an apparent thermal bar condition could be seen, with a line of water color change lying outside of the Cook survey area. On the survey date, surface temperatures were 9.0°C inshore and decreased to 6.7°C at the deepest stations. Subsurface temperatures fell gradually with depth, the bottom usually being about 2°C colder than the surface. At no station did Secchi depths exceed 3.0 m. Phytoplankton averaged 1200 cells/ml inshore and abundances were only slightly less offshore.

We found several differences in zooplankton composition which may be

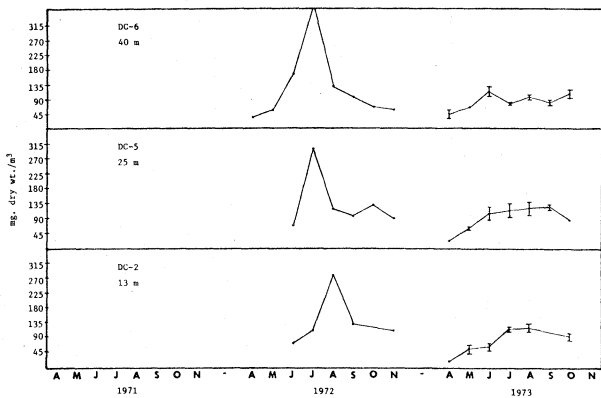


FIGURE 4. Seasonal distribution of zooplankton biomass at three stations.

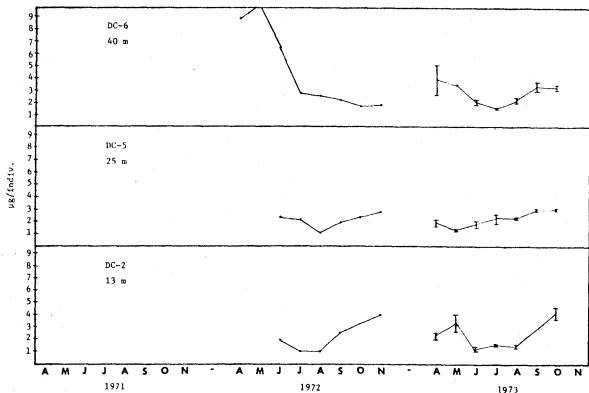


FIGURE 5. Seasonal distribution of mean dry weight per animal at three stations.

associated with these warmer conditions. Most notable was the larger numbers of copepod nauplii--about $5000/m^3$ at most stations. This is two to four times the numbers found inshore in 1971 and 1972, and ten times the number previously found offshore. Nauplii made up more than 50% of the population and were chiefly responsible for total abundances being higher than in past years. As in the past, the April fauna was composed almost entirely of *Cyclops bicuspidatus* and four species of *Diaptomus*. *Cyclops* were found offshore in numbers similar to previous years ($1000/m^3$) but both adult and immature copepods were strongly reduced in numbers close to shore (Fig. 6 and 7). This is another possible consequence of the warmer conditions. Immature *Diaptomus* were less abundant at shallow stations (Fig. 8). Adults of *Diaptomus* spp. generally exceeded $2000/m^3$ at the deeper stations and decreased to $1000/m^3$ inshore (Fig. 9). These numbers were similar to those obtained in past years, but numbers of immature *Diaptomus* were five times as large (about $1000/m^3$). As in past Aprils, *D. ashlandi* was the dominant diaptomid. All 4 species showed evidence of reproductive activity (eggs or spermatophores) and the numbers of reproductive females seemed to be higher on this date than at other times during the year. Immature copepodids of both *Diaptomus* and *Cyclops* were predominantly first and second instars. April was the only month in which immature copepods did not greatly exceed adults in number.

As in the past, numbers of adult *Limnocalanus* were low ($20/m^3$ offshore). Most individuals were judged to be survivors of the previous generation rather than newly matured adults. Immature *Limnocalanus* numbered $220/m^3$ offshore, $140/m^3$ inshore, and 0 in the littoral zone. Only early instars could be found at the inshore stations. April was the only month in which *Limnocalanus* nauplii were seen in abundance ($400/m^3$ offshore).

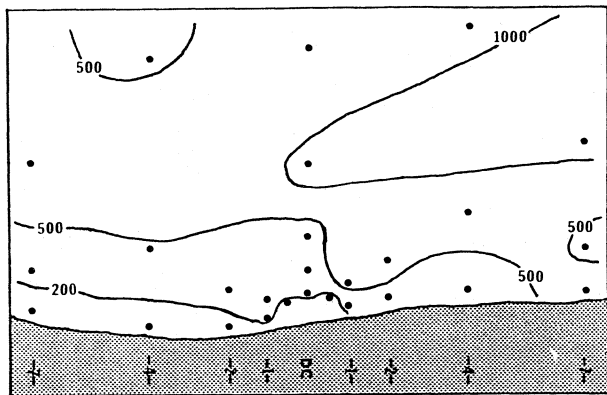


FIGURE 6. Horizontal distribution of *Cyclops* C1-C5 ($\#/m^3$), 25 April 1973.

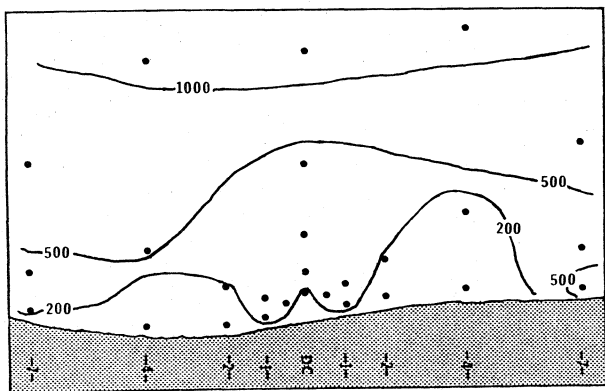


FIGURE 7. Horizontal distribution of adult *Cyclops* ($\#/m^3$), 25 April 1973.

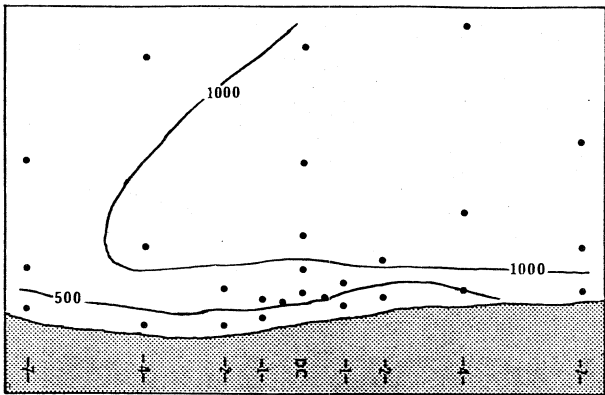


FIGURE 8. Horizontal distribution of *Diaptomus* C1-C5 (#/m³), 25 April 1973.

0 5
KM

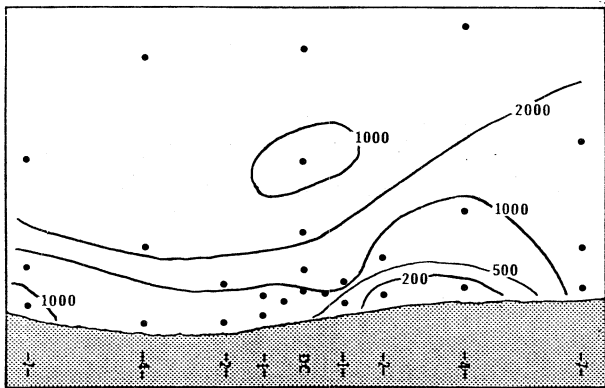


FIGURE 9. Horizontal distribution of adult *Diaptomus* (#/m³), 25 April 1973.

Some genera overwinter in very small numbers--*Tropocyclops*, *Bosmina*, *Eubosmina*, *Daphnia*, *Asplanchna*. These were found in the April survey samples; but with the exception of *Bosmina*, they had not begun to increase their population sizes above winter levels. *Bosmina longirostris* was found at all stations in numbers that averaged $50/m^3$ through most of the survey area and surpassed $100/m^3$ in the littoral zone (Fig. 10). These abundances are small in comparison with summer conditions but are larger than previously noted in April.

In addition to the tendency of all the copepods to be more numerous offshore, there was a general trend for total abundances to be greater toward the north (Fig. 11).

THE SHORT SURVEY OF 17 MAY 1973

A period of cool weather in the early part of the month held temperature increases to about 2°C above April levels. As in April, subsurface water temperatures declined gradually with depth and were 2°C colder at the bottom of the column. Secchi depths were close to 1.0 m inshore and increased to 4.5 m offshore. Phytoplankton cell counts were likewise lower as distance from shore increased.

Copepod reproduction appeared to be continuing unabated for, while numbers of adult *Cyclops* and *Diaptomus* remained similar to those in April, numbers of nauplii had increased to $10,000/m^3$ and numbers of immature copepodids increased by a factor of 5. These changes resulted in total abundances ranging from $27,000/m^3$ inshore to $19,000/m^3$ offshore. On the May 1972 survey date, temperatures resembled those of April and zooplankton averaged only $6000/m^3$.

The *Limnocalanus* population was similar in size to that found in April but more late instars and fewer early instars were found. A few *Eurytemora* immatures were encountered, and these were predominantly first instar copepodids. *Bosmina*

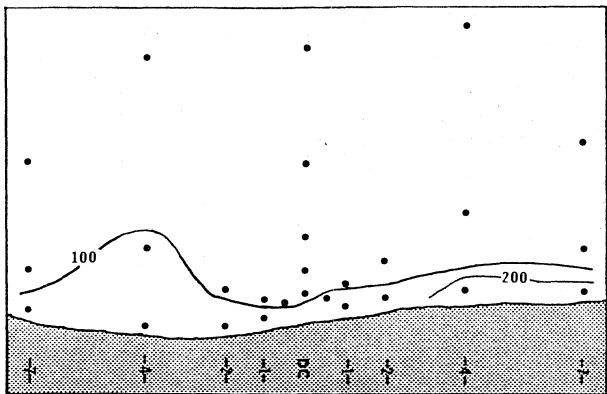


FIGURE 10. Horizontal distribution of *Bosmina* ($\#/m^3$), 25 April 1973.

0 5
KM

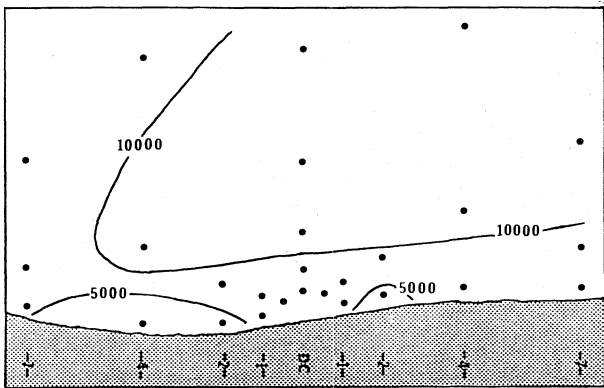


FIGURE 11. Horizontal distribution of total zooplankton ($\#/m^3$), 25 April 1973.

was the only cladoceran genus of note, its numbers having increased to 400/m³ inshore, 150/m³ offshore. Much lower populations of all species were found in the littoral zone.

THE SHORT SURVEY OF 20 JUNE 1973

Although bathythermographs are not available, it is evident that the waters in the survey area were thermally stratified by this date. Surface temperatures had increased by 11° over May readings—to 22°C inshore and 18.5°C offshore. Calm, sunny conditions undoubtedly resulted in a settling of suspended material, for Secchi disc readings were the highest of the season, ranging from 3.0 m inshore to 8.0 m offshore.

It may be inferred that copepods were strongly stratified in their vertical distribution; there was a regular increase with increasing station depth. Immature *Cyclops* numbered 1500/m³ in the littoral zone, 6500/m³ in the inshore zone, and 15,000/m³ offshore. Numbers of adult *Cyclops* progressed from 100/m³ to 1700/m³ to 3200/m³. *Diaptomus* immatures were 3000/m³ in the littoral zone, 11,000/m³ inshore, and 20,000/m³ offshore. Abundance of adult *Diaptomus* went from 800/m³ to 2700/m³ to 4000/m³. Both adults and immatures were more abundant than on the June 1972 survey date. *Diaptomus ashlandi* continued to dominate offshore but was strongly reduced inshore. In the littoral zone, *Diaptomus minutus* was the only calanoid copepod in abundance.

On 20 June, the first adult *Cyclops vernalis*, *Epischura*, and *Eurytemora* were seen. *Limnocalanus* adults were in greater abundance than immatures for the first time, and all of these adults appeared to be newly matured individuals. *Bosmina* increased by factors of 20 to 40 over May abundances, with the largest increase occurring in the inshore zone where counts reached 19,000/m³. The rotifer *Asplanchna* underwent a similar large increase in the inshore region,

and rotifers in general seemed to be most abundant during this month. Numbers of *Daphnia* had increased somewhat but remained low ($100/\text{m}^3$). *Leptodera* and *Polyphemus* made their first appearance on this date.

On the whole, numbers of cladocera were close to those observed in 1972; but due to the larger standing crops of copepods, total numbers were more than twice as high ($50,000/\text{m}^3$ vs. $20,000/\text{m}^3$).

THE MAJOR SURVEY OF 19 JULY 1973

This collection date fell midway between the two principal periods of near-shore upwelling that occurred in July. The weather was hot and calm with surface temperatures between 23 and 25°C. Secchi disc depths were 2.0 m inshore, increasing to 6.0 m offshore. Inshore phytoplankton counts were much higher than those of 1972--up to 4000/ml at some stations.

As in 1971 and 1972, total abundances of zooplankton in the offshore region reached their yearly maximum in July. This was $72,000/\text{m}^3$, a figure only half as large as that attained in 1972 but as large or larger than offshore abundances in July 1971. Inshore and littoral zone totals ($67,000/\text{m}^3$) were two-thirds the 1971 and 1972 figures (Fig. 12). Dry weights were below $100 \text{ mg}/\text{m}^3$ at the littoral zone stations and generally between 100 and $200 \text{ mg}/\text{m}^3$ at the remaining stations (Fig. 13).

Numbers of nauplii, immature and adult *Cyclops*, and immature *Diaptomus* were notably lower than in 1972, but similar to or greater than numbers found in 1971. Among the calanoid copepods, *Diaptomus minutus* was as abundant as *D. ashlandi* offshore ($>1000/\text{m}^3$) and exceeded *D. ashlandi* inshore. As may be seen in Figures 14, 15, 16, and 17, adult *Cyclops* and *Diaptomus* were concentrated offshore; immatures showed the same tendency but less strongly.

The second major cyclopoid, *Tropocyclops prasinus*, had begun to increase

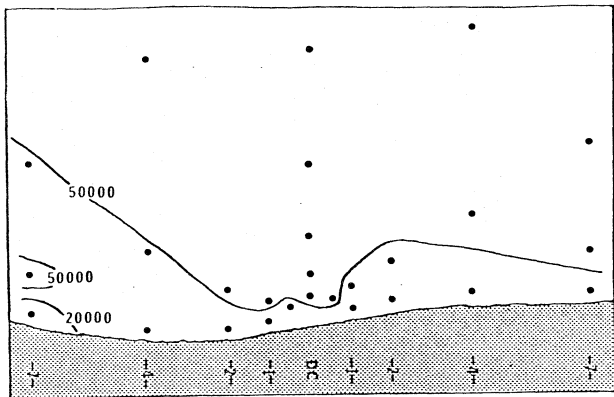


FIGURE 12. Horizontal distribution of total zooplankton (#/m^3), 19 July 1973.

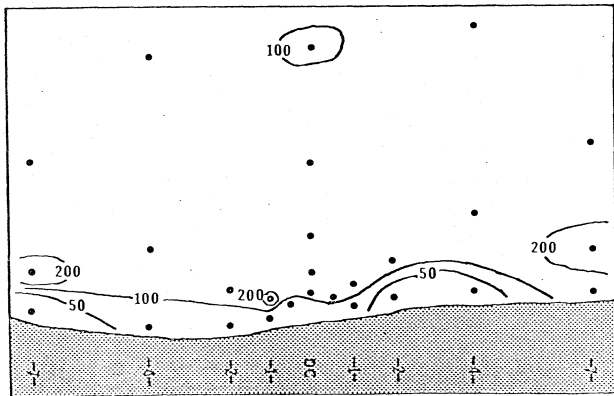


FIGURE 13. Horizontal distribution of zooplankton biomass (mg/m^3), 19 July 1973.

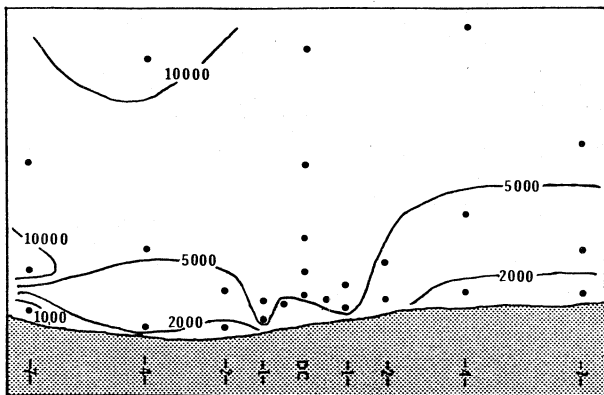


FIGURE 14. Horizontal distribution of *Cyclops* C1-C5 ($\#/m^3$), 19 July 1973.

0 5
KM

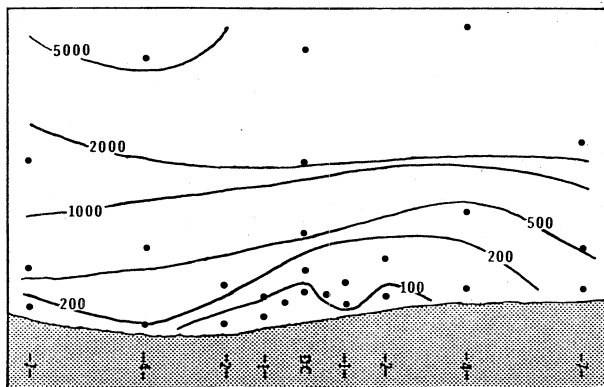


FIGURE 15. Horizontal distribution of adult *Cyclops* ($\#/m^3$), 19 July 1973.

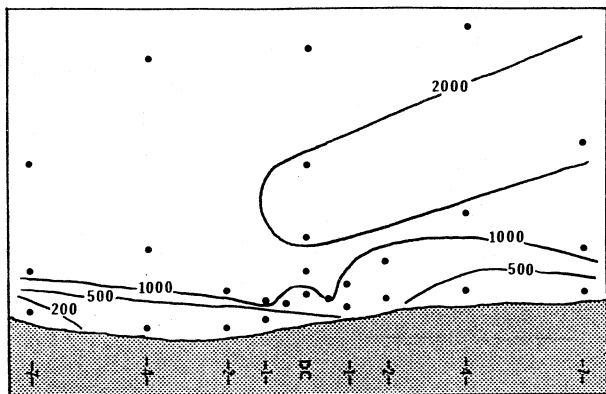


FIGURE 16. Horizontal distribution of *Diaptomus* Cl-C5 ($\#/m^3$), 19 July 1973.

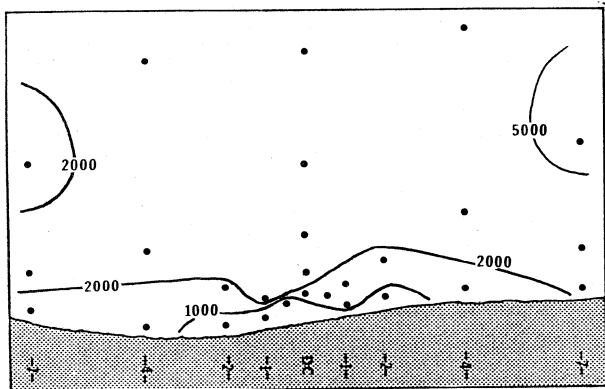


FIGURE 17. Horizontal distribution of adult *Diaptomus* ($\#/m^3$), 19 July 1973.

its population size by July. We found averages of $400/\text{m}^3$. Abundance of the large calanoid *Limnocalanus macrurus* was $120/\text{m}^3$ offshore, almost all of which were adults. This is the last month in which immature *Limnocalanus* were seen.

The most interesting find was one which had been suspected but not determined quantitatively in past years. *Eurytemora affinis* immatures were, in comparison with other months, very abundant in July. What is more, this sudden surge in numbers of *Eurytemora* was localized close to shore; abundances were $1100/\text{m}^3$ in the littoral zone, $800/\text{m}^3$ inshore, and $100/\text{m}^3$ offshore. Since the more abundant calanoid copepods are reduced close to shore, *Eurytemora* approached the relative importance of *Diaptomus* at the shallowest stations. A yearly maximum of adult *Eurytemora*, $250/\text{m}^3$ inshore, coincided with the peak in numbers of immatures.

The chief difference between this survey and that of July 1972 was in the smaller numbers of *Bosmina* found. Populations were between $10,000/\text{m}^3$ and $30,000/\text{m}^3$ throughout the survey area (Fig. 18), amounting to 25-50% of the total, whereas in past years *Bosmina* populations reached 50,000 or more and comprised 50-80% of the total. A second cladoceran species reaching a July maximum was the predaceous *Polyphemus pediculus*. Most other cladoceran species had begun to increase in abundance by the July date. *Daphnia* generally numbered $800/\text{m}^3$ (Fig. 19), most of the increase being in numbers of *D. retrocurva*.

The rotifer *Asplanchna priodonta*, at $1000/\text{m}^3$ was slightly less abundant than in past July surveys. Its horizontal distribution had an interesting and unexplained pattern of localized abundance toward the north (Fig. 20).

THE SHORT SURVEY OF 23 AUGUST 1973

This survey was made during a period of upwelling. Water temperatures were below normal August values and were colder inshore (16.4°C) than offshore (19.7°C).

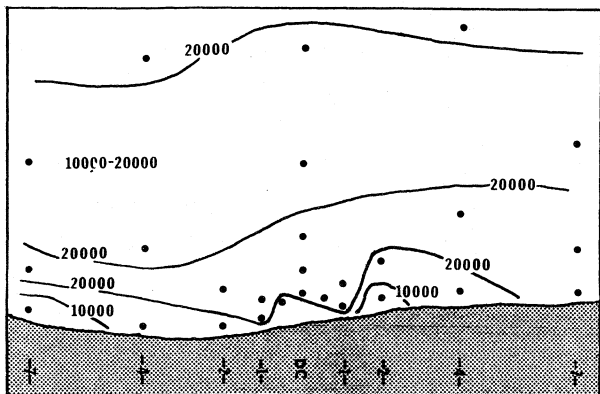


FIGURE 18. Horizontal distribution of *Bosmina* (#/m³), 19 July 1973.

0 5
KM

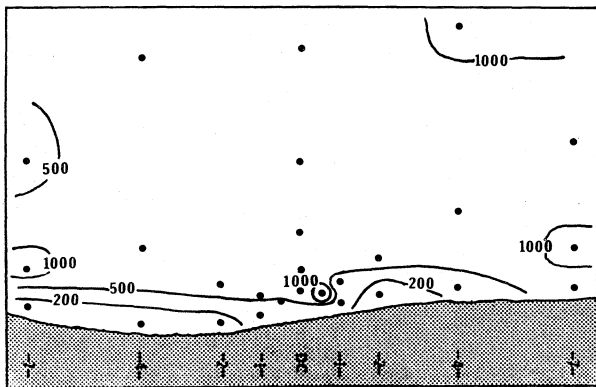


FIGURE 19. Horizontal distribution of *Daphnia* spp. (#/m³), 19 July 1973.

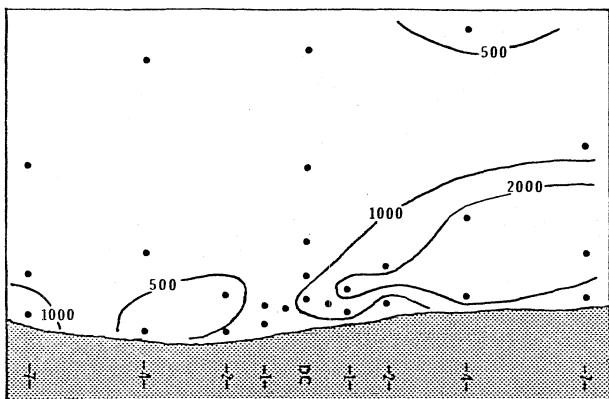
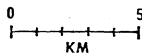


FIGURE 20. Horizontal distribution of *Asplanchna* (#/m³), 19 July 1973.



Secchi depths were close to 2.5 m throughout the survey area. Phytoplankton counts were generally between 1000 and 2000 cells/ml.

As in 1972, inshore and littoral zone zooplankton reached their maximum abundance in this month. Copepods were similar in number but, because populations of *Bosmina* had declined greatly from July levels, the magnitudes of these August peaks were less than those of the large peaks seen in 1972. The August fauna was dominated by immature copepods in all zones. Nauplii and immature cyclopoid copepodids were particularly abundant in the two shallow zones where they averaged 17,000/m³ and 25,000/m³ respectively. *Cyclops* and *Diaptomus* were as abundant inshore as offshore, a possible consequence of the upwelling condition. The hypolimnetic *Limnocalanus* was found in greater numbers than usual at the offshore station (370/m³) but did not show up in samples collected inshore.

In 1972, the characteristically July genera *Bosmina*, *Eurytemora*, *Polyphemus*, and *Asplanchna* continued to increase their populations into August, then declined sharply between August and September. In 1973 all of these species had undergone a marked decline by the time of the August survey. In the inshore zone where it was most common, *Bosmina* amounted to only 2500 individuals per cubic meter. This left the species of *Daphnia*, predominantly *D. retrocurva*, as the most important cladocerans. *Daphnia* totaled 9000/m³ in the inshore and littoral zones, 4000/m³ offshore. *Diaphanosoma*, *Eubosmina*, *Holopedium*, and *Leptodora*, although not common, appeared with regularity in all samples collected in August. *Ceriodaphnia quadrangulare*, a regular constituent of the late summer collections of 1972, remained rare in this and all other months of 1973.

THE SHORT SURVEY OF 20 SEPTEMBER 1973

Water temperatures had decreased to about 15°C on 20 September. An apparently well mixed epilimnion extended to a depth of 25 m. Thus 15 m of

6.5°C hypolimnetic water were beneath the offshore station, DC-6, but only epilimnetic water was sampled at all other stations. Secchi depths ranged from 2.0 m inshore to 4.0 offshore, and phytoplankton abundance was a nearly uniform 1200 cells/ml throughout the survey area.

Zooplankton diversity is usually highest in the autumn. On this date 19 of the 21 common species were present, the exceptions being *Ceriodaphnia* and the harpacticoid copepod *Canthocamptus*. Total numbers inshore ($61,000/\text{m}^3$) were similar to those found in past years, while total numbers offshore ($24,000/\text{m}^3$) were smaller by a factor of two to three. Copepod nauplii were scarce in past fall surveys, and this was the case in 1973. Only 1400 nauplii/ m^3 were found inshore and less than 400/ m^3 were noted offshore. Numbers of *Cyclops* were similar to those seen in past years (10,000 immatures/ m^3 , 1500 adults/ m^3) but numbers of *Diaptomus* were lower by a factor of two.

Bosmina and *Asplanchna* recovered from their August lows, *Bosmina* reaching $20,000/\text{m}^3$ and *Asplanchna* $4000/\text{m}^3$, but this second pulse was confined to the shallow stations. This was the only month in which substantial numbers of *Chydorus* were seen-- $300/\text{m}^3$ in the littoral zone, $100/\text{m}^3$ inshore. *Daphnia*, still predominantly *D. retrocurva*, reached their yearly maximum of $11,000/\text{m}^3$ in the inshore zone. This number is close to the maxima attained by this genus in 1971 and 1972. The same may be said of *Diaphanosoma* ($600/\text{m}^3$ inshore) and *Leptodera* ($180/\text{m}^3$ in the littoral zone). In past years *Holopedium gibberum* has been most abundant in September, reaching $5000/\text{m}^3$ in 1971 and $2700/\text{m}^3$ in 1972. In 1973, few samples contained *Holopedium* in numbers greater than $50/\text{m}^3$.

THE MAJOR SURVEY OF 23 OCTOBER 1973

Warm weather prevailed during the first two weeks of October and resulted in water temperatures that were as high as those in September, 15°C. Secchi

depths of about 2.0 m inshore accompanied phytoplankton abundances of 2000 cells/ml, while offshore readings of 5.5 m accompanied algal counts of 500 cells/ml.

Offshore dominance by copepods was balanced by inshore dominance of cladocera, producing a nearly unvarying distribution of total numbers (Fig. 21). Average offshore abundance was $41,000/m^3$, the average inshore was $30,000/m^3$. These numbers are a little smaller than the figures of $40-50,000/m^3$ obtained in 1972. Biomass was also evenly distributed (Fig. 22), although a few weights greater than $200\text{ mg}/m^3$ were obtained in the littoral zone. These samples may have been contaminated with filamentous algae.

Numbers of nauplii continued to decline, falling to $600/m^3$ in October. Another signal of decreasing copepod reproduction was the smaller numbers of early instar copepodids of both *Cyclops* and *Diaptomus*. Both adults and immatures of these species were present in greatest concentrations at the deeper stations (Figs. 23, 24, 25, and 26). As was the case in September, *Cyclops bicuspidatus* at $11-17,000/m^3$ was as abundant as in 1972, while diaptomids at $7-14,000/m^3$ were only half as abundant. Adults of both *Diaptomus ashlandi* and *D. minutus* declined to what is probably a yearly low. The most common *Diaptomus* species was *D. oregonensis* ($530/m^3$ offshore). Both this species and *D. sicilis* typically are most abundant in the late fall. Another fall-maturing calanoid, *Epischura lacustris*, was seen in maximum numbers ($180/m^3$) on 23 October.

Among the cladocerans, *Bosmina longirostris* was matched in abundance by the related species *Eubosmina coregoni*. As may be seen in Figures 27 and 28, both species were most numerous in the littoral zone ($6000/m^3$) and least abundant offshore ($1200/m^3$). The two *Daphnia* species were in nearly equal abundance ($1000/m^3$). *Daphnia retrocurva* typically declines from its August and September maxima as the fall progresses while *D. galeata* increases. Horizontal distribution

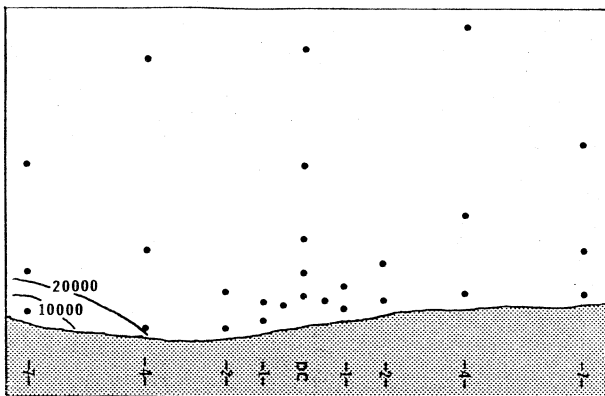


FIGURE 21. Horizontal distribution of total zooplankton ($\#/m^3$), 23 October 1973.

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KM

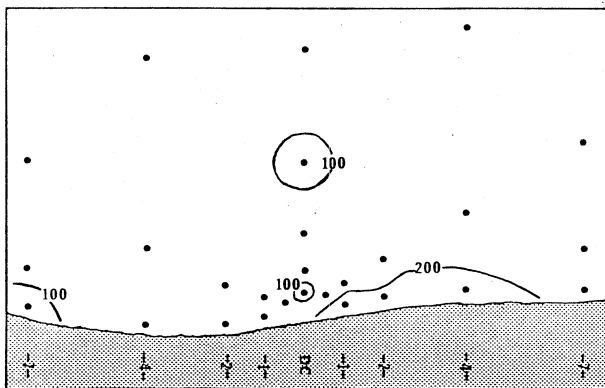


FIGURE 22. Horizontal distribution of zooplankton biomass (mg/m^3), 23 October 1973.

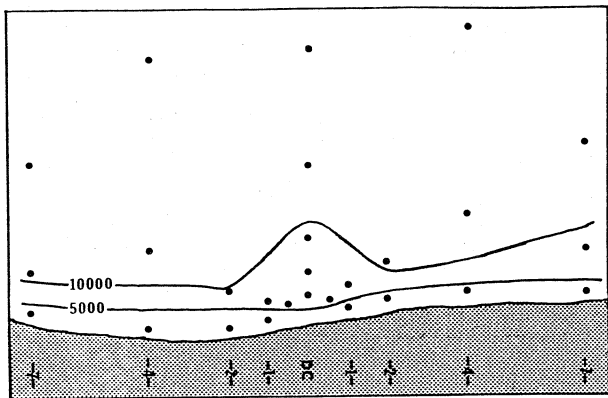


FIGURE 23. Horizontal distribution of *Cyclops* Cl-C5 ($\#/m^3$), 23 October 1973.

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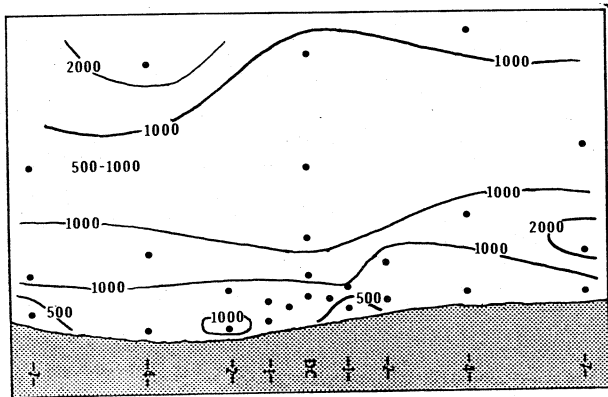


FIGURE 24. Horizontal distribution of adult *Cyclops* ($\#/m^3$), 23 October 1973.

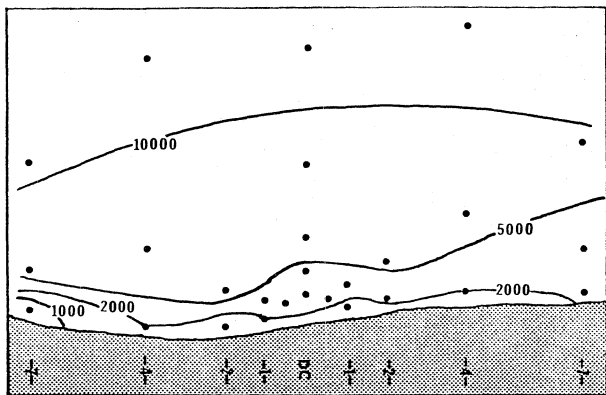


FIGURE 25. Horizontal distribution of *Diaptomus* C1-C5 ($\#/m^3$), 23 October 1973.

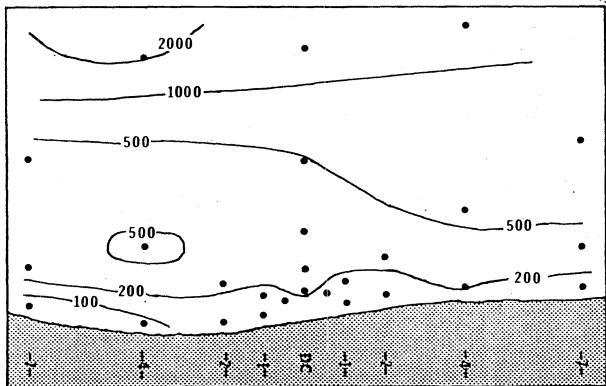


FIGURE 26. Horizontal distribution of adult *Diaptomus* ($\#/m^3$), 23 October 1973.

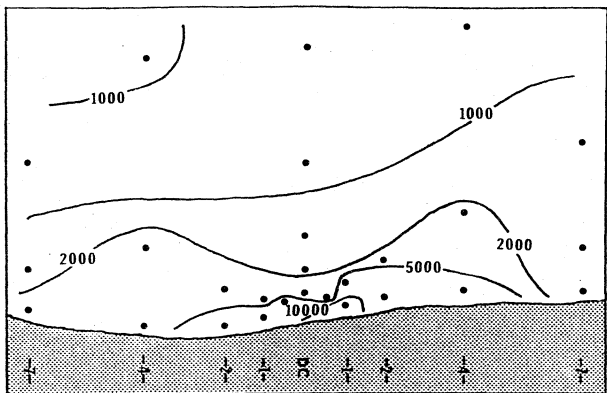


FIGURE 27. Horizontal distribution of *Scaevinia* ($\#/m^3$), 23 October 1973.

0 5
KM

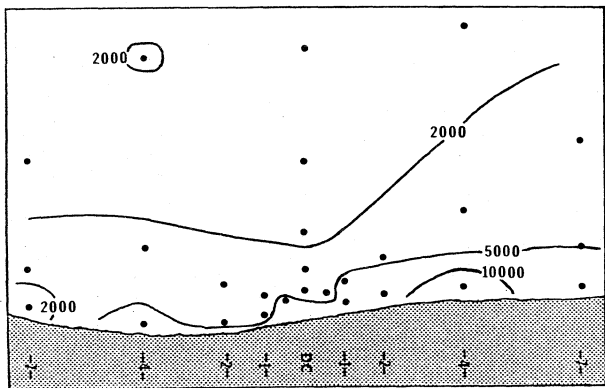


FIGURE 28. Horizontal distribution of *Eubosmina* ($\#/m^3$), 23 October 1973.

of *Daphnia* is mapped in Figure 29. Other species, while present in sufficient numbers to produce a high October diversity, had declined from their August and September abundances and were relatively unimportant. The rotifer *Asplanchna* was most abundant away from shore (Fig. 30).

Male *Daphnia* were common in the October samples, but females were not yet ephippial. Males of *Bosmina*, *Eubosmina*, *Diaphanosoma*, and *Leptodera* were seen with less frequency, and again ephippical females were absent. *Asplanchna* had not yet begun to produce resting eggs.

NIGHT ZOOPLANKTON

Since our samples are collected in the form of vertical hauls, time of day is not expected to greatly bias estimates of population sizes. However, there are three factors which might produce differences between day and night: (1) Benthic organisms may leave the bottom and enter the plankton at night. (2) The lower one or two meters are inadequately sampled. Species aggregated here during the day would be under-represented. (3) Animals migrating upward from deep water at night may be diffused shoreward. The latter is probably not great enough to produce day/night cycles for, while exchange of water undoubtedly takes place, it still permits the maintenance of chemical, phytoplankton, and zooplankton differences between the inshore and offshore regions. The first two possibilities are likely and, in order to investigate their magnitude, we collected a separate series of samples in 1973.

On 16 July, the date of the major survey, additional visits were made to stations DC-2 (12 m), DC-5 (23 m), and DC-6 (37 m) between the hours of 2042 and 2110. Three vertical hauls were taken at each station, using collection methods identical to those described for the field study. Subsampling, identification,

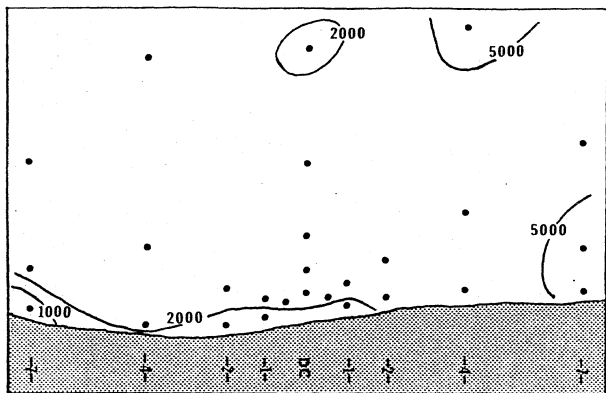


FIGURE 29. Horizontal distribution of *Daphnia* spp. ($\#/m^3$), 23 October 1973.

0 5
KM

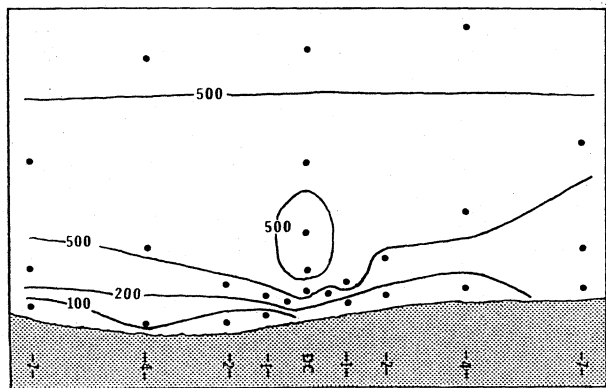


FIGURE 30. Horizontal distribution of *Asplanchna* ($\#/m^3$), 23 October 1973.

and counting were carried out using the same methods. In addition, from one-fourth to the entire sample was inspected for *Mysis* and *Pontoporeia*. Table 10 compares the mean abundance of each species caught at these stations in the evening with its abundance during the daylight hours. A student's t-test was used to test the hypothesis that the means are equal. This test is relatively insensitive to nonnormality of the sort likely to be exhibited by these data, but in the case of differences of interest (*Mysis*, *Limnocalanus*, *Eurycerus*) we repeated the test using a log (x+1) transformation to verify the significance.

DC-6 (37 METERS)

Total numbers of zooplankters at this offshore station were virtually identical at the two times, the difference being about 1%. *Tropocyclops*, *Daphnia*, and *Leptodora* were two to three times as abundant at night. This is a statistically significant difference, but a difference that is not likely to be meaningful. These species generally inhabit the upper water layers and are distributed with sufficient patchiness that differences of this magnitude can often be found between two stations of the same depth. The opossum shrimp *Myside relicta* was absent from all replicates taken at this station during the day, but occurred with an abundance of $6.8/\text{m}^3$ in the night plankton. *Mysis* is an epibenthic organism whose nocturnal migrations are well known. A volumetric abundance of $6.8/\text{m}^3$ is equivalent to an areal abundance of $250/\text{m}^2$ --a population estimate as large or larger than is generally obtained with grab samples at this station. The benthic amphipod *Pontoporeia affinis* was present in these samples in only miniscule numbers ($<0.1/\text{m}^3$). Given the large populations known from grab samples to be present at this depth, entry of *Pontoporeia* into the night plankton must be negligible at this time of year. A three-fold and highly significant increase in the numbers of the large copepod *Limnocalanus macrurus*

TABLE 10. Mean abundances in $\#/\text{m}^3$ and mean dry weights in mg/m^3 and $\mu\text{g}/\text{individual}$ for day and night zooplankton samples collected at three stations on July 19, 1973. Significance of day/night differences was evaluated with a t-test and the results are listed. Each sample consisted of three replicates.

	DC-2 (12m)			% chg	DC-5 (23m)			% chg	DC-6 (37m)			% chg
	Day	Night	P		Day	Night	P		Day	Night	P	
Copepod nauplii	17869	6374	<.001	- 64	7924	10208	<.05	+ 29	7020	7553	ns	
Cyclopoid copepods												
<i>Cyclops</i> CI-C5	11705	3827	<.01	- 67	6213	8234	ns		6939	7411	ns	
<i>Cyclops bicuspidatus thomasi</i>	43	212	ns		2017	2746	ns		2146	2718	ns	
<i>Cyclops vernalis</i>	6	163	ns		30	25	ns		0	0	ns	
<i>Tropocyclops prasinus mexicanus</i>	994	338	ns		325	543	ns		210	450	<.01	+114
Calanoid copepods												
<i>Diaptomus</i> CI-C5	8279	7935	ns		21012	21592	ns		13355	13788	ns	
<i>Diaptomus ahlandi</i>	199	728	<.01	+266	2514	2264	ns		1108	1272	ns	
<i>Diaptomus minutus</i>	991	987	ns		1586	1941	ns		925	1272	ns	
<i>Diaptomus oregonensis</i>	103	81	ns		372	319	ns		208	352	ns	
<i>Diaptomus stollis</i>	0	12	ns		36	12	ns		40	67	ns	
<i>Epsilohuxia</i> CI-C5	6	17	ns		25	19	ns		16	0	ns	
<i>Epsilohuxia lacustris</i>	3	5	ns		0	6	ns		4	4	ns	
<i>Eurytemora</i> CI-C5	2118	945	<.01	- 55	50	163	ns		49	20	ns	
<i>Eurytemora affinis</i>	341	314	ns		69	56	ns		17	24	ns	
<i>Limnocalanus</i> CI-C5	0	0	ns		0	0	ns		0	4	ns	
<i>Limnocalanus macrurus</i>	0	6	ns		191	229	ns		73	237	<.001	+225
Cladocerans												
<i>Alona affinis</i>	12	6	ns		0	0	ns		0	0	ns	
<i>Boeckia longirostris</i>	26510	31331	<.01	+ 18	9160	17420	<.001	+ 90	17311	13875	<.05	- 20
<i>Chydorus</i> spheeriscus	19	16	ns		0	0	ns		0	8	ns	
<i>Daphnia galeata mendotae</i>	30	41	ns		179	124	ns		92	277	<.01	+201
<i>Daphnia retrocurva</i>	922	1435	<.05	+ 56	339	628	ns		396	932	<.02	+135
<i>Daphnia rosea leachenbergianum</i>	22	0	ns		0	0	ns		0	0	ns	
<i>Eubosmina coregoni</i>	105	81	ns		94	100	ns		163	182	ns	
<i>Eurycerus lamellatus</i>	30	594	<.001	+1880	0	0	ns		0	0	ns	
<i>Holopedium gibberum</i>	18	118	<.02	+556	104	106	ns		81	130	ns	
<i>Leptodora kindtii</i>	37	29	ns		24	0	ns		16	59	<.05	+269
<i>Polphemus pediculus</i>	196	315	ns		30	106	ns		52	83	ns	
Rotifers												
<i>Asplanchna priodonta</i>	1862	3226	ns		832	1093	ns		672	933	ns	
Malacostracans												
<i>Neis relicta</i>	0	0	ns		0	4.7	<.01		0	6.8	<.02	
TOTAL	72427	59137	<.01	- 18	53127	67971	<.05	+ 28	50901	51662	ns	
dry wt. (mg/m^3)	113.5	133.9	ns		114.6	132.5	ns		78.1	111.5	ns	
dry wt. ($\mu\text{g}/\text{individual}$)	1.5	2.3			2.2	2.0			1.6	2.2		

occurred from day to night. Since this organism inhabits the deepest part of the water column, inadequate near-bottom sampling may account for the difference. Smaller night increases in numbers of *Limnocalanus* were also seen at stations DC-5 and DC-2. Zooplankton biomass at DC-6 increased from 78 to 112 mg dry weight/m³ at night. This increase was probably due almost entirely to the numbers of *Mysis* and *Limnocalanus* in the night samples.

DC-5 (23 METERS)

A night increase of about 28% in total numbers at this station was due to the greater abundance of *Boeckia* and of copepod nauplii. Again, this sort of difference can be interpreted as plankton patchiness. The one statistically significant increase of interest is the change in numbers of *Mysis relicta*. None were seen in the daytime samples; 4.7/m³ or 104/m² were found in the night samples. Zooplankton biomass increased from 115 to 132 mg dry weight/m³.

DC-2 (12 METERS)

This station is of particular interest since it is located close to the Cook intake structures. Here total numbers decreased from day to night by a factor of 18%, most of the difference being accounted for by changes in the number of immature copepods. We attribute these decreases to patchiness. Changes in numbers of *Diaptomus ashlandi* such as the three-fold increase seen here may be a recurring feature of the inshore night plankton, since this species appears to avoid the upper water layers during the day. But we have only limited confidence in this prediction. *Mysis* and *Pontoporeia* were both absent from night samples collected at DC-2 and *Limnocalanus* appeared only in small numbers. The one interesting find at this station was the highly significant increase in numbers of the large benthic cladoceran, *Euryceerus lamellatus*, from 30/m³ to almost 600/m³ (7200/m²). Since biomass increased from 114 to

134 mg dry weight/m³ while total numbers declined, at least half of the increase can be attributed to the presence of *Eurycerus* at night. Thus *Eurycerus* would make up about 10% by weight of the night zooplankton. One hundred *Eurycerus* were picked from a sample, dried and found to weigh an average of 18 micrograms per individual, lending support to this inference.

Although abundances within the entire column may change little, nocturnal migrations produce striking changes in depth distribution. This is illustrated by Table 11 where comparison is made between day and night population estimates obtained from tows of a #2 mesh net 1 m below the water's surface. These samples were part of a much more extensive series taken for the purpose of determining abundance of larval fish. The methods used are discussed in detail elsewhere (see Jude et al. 1974). Stations D and C are located near the Cook Plant at depths of 9 and 6 m. Station G is located off Warren Dunes State Park at a depth of 6 m. Since the more abundant zooplankton species are not sampled quantitatively by a net with 371 micron apertures we considered only the largest species, our interest being concentrated on *Eurycerus*.

Entry of *Eurycerus lamellatus* and a second large benthic cladoceran *Alona affinis* into the night plankton appears to be a regular feature of the littoral zone during the summer months. Both species were either rare or did not leave the bottom on the collection dates in April and October. With the exception of *Polyphemus*, the holoplanktonic species were seen to congregate near the surface in numbers several times greater than their daytime abundance. The night sample collected at station C in August is of some interest, for it was taken at the height of a period of nearshore upwelling. It contained relatively larger numbers of the copepods *Epischura lacustris* and *Limnocalanus* and relatively smaller numbers of cladocerans. Station G was visited the following day, 22 August, and the vertical hauls were taken on 23 August.

TABLE 11. Abundance in numbers per m³ of some large, uncommon zooplankton species collected in day/night horizontal tows one meter beneath the surface (stations D,C,G) and in daytime vertical hauls (V.H.) at survey stations less than 10 meters in depth.

	V.H. day	Station D day night		Station C day night		Station G day night	
April							
<i>Limnocalanus</i>	0	3	0	1	0	2	0
<i>Alona</i>	0	0	0	0	0	0	0
<i>Eurycercus</i>	2	0	0	0	0	2	1
June							
<i>Epischura</i>	0	0	4	2	1		
<i>Eurytemora</i>	0	3	4	1	34		
<i>Limnocalanus</i>	1	0	12	0	0		
<i>Alona</i>	0	0	0	0	43		
<i>Eurycercus</i>	0	0	65	0	187		
<i>Holopedium</i>	0	0	1	0	1		
<i>Leptodora</i>	0	0	0	0	1		
<i>Polyphemus</i>	16	35	9	79	18		
July							
<i>Epischura</i>	6	2	16	0	35		
<i>Eurytemora</i>	67	8	105	6	81		
<i>Limnocalanus</i>	9	0	1	0	1		
<i>Alona</i>	5	0	250	0	2		
<i>Eurycercus</i>	0	2	791	0	301		
<i>Holopedium</i>	37	0	6	2	4		
<i>Leptodora</i>	20	0	6	0	43		
<i>Polyphemus</i>	381	176	127	95	191		
August							
<i>Epischura</i>	6			37	377	1	13
<i>Eurytemora</i>	20			0	1	0	0
<i>Limnocalanus</i>	0			1	18	0	1
<i>Alona</i>	0			0	1	0	0
<i>Eurycercus</i>	0			1	20	0	58
<i>Holopedium</i>	99			4	8	11	18
<i>Leptodora</i>	198			1	65	21	284
<i>Polyphemus</i>	40			0	0	3	0
October							
<i>Limnocalanus</i>	0			0	3		
<i>Alona</i>	0			0	0		
<i>Eurycercus</i>	0			0	0		

On the basis of these results, we would expect that zooplankton entrained into the Cook Plant cooling system will exhibit day/night differences to the extent that water enters the intake structures from a restricted layer. If, as has been predicted, the water is drawn from the entire column, then the major difference occurring in the summer is likely to be a nighttime increase in the numbers of *Daphnia* and, to a smaller extent, *Alona*.

VERTICAL DISTRIBUTION

Patterns of horizontal distribution such as those illustrated in Figures 6 through 30 reveal abundance to be a function of station depth. In part this is due to physical, chemical, and biological differences between inshore and offshore waters, in part it is an artifact of vertical haul sampling. Species most abundant in the upper water strata can be expected to be over-represented at shallow stations and under-represented at deep stations. Hence knowledge of the patterns of vertical distribution exhibited by the Lake Michigan species is of value when interpreting results of the field surveys. Most studies have shown vertical distributions to undergo complex daily and seasonal rearrangements. Thus nothing other than broad generalizations about the principal species in the Cook area could be made without an intensive sampling effort. What we sought with the separate series of samples reported in this section is a broad idea of the offshore daytime vertical distribution on a summer date.

On 23 August, the date of the short survey, six additional vertical hauls were made at the 43-m station DC-6. In addition to the hauls which sampled the entire water column, three hauls were taken through the upper 20 m, and three replicate samples were made of the upper 8 m. The latter two depths were calculated from the amount of line played out and the angle at which the net was

retrieved. Each sample was counted using the methods described for the field study.

These short hauls, together with vertical hauls at shallower stations, provide a means of comparing abundances in the same water stratum inshore and offshore. In addition one can calculate, by a subtraction process, abundance by depth interval at the offshore station. Differences in mean numbers of animals captured in long and short hauls were divided by differences in volumes of water represented by the samples. The results of these computations are presented graphically in Figures 31, 32, and 33.

Position of the thermocline on this date is not known. A typical August depth would be 20 m, but, since the inshore region showed evidence of strong upwelling during the two previous days, the epilimnion at DC-6 may have been shallower.

Zooplankton were most concentrated, both by total numbers and by biomass, at the middle depth. Chief contributors to this concentration were adults and immature copepodids of *Cyclops bicuspidatus*, immature diaptomids, *Diaptomus ashlandi* and *Daphnia retrocurva*. Only two species were more abundant in the deepest stratum, *Limnocalanus macrurus* and *Diaptomus sicilis*, *Limnocalanus* being restricted to the hypolimnion. Most cladoceran species, as well as the rotifer *Asplanchna*, favored the uppermost layer, but with the exception of the four species represented in Figure 33 were found in only small numbers. *Holopedium*, whose gelatinous sheath reduces its specific gravity, showed a particularly strong preference for the near-surface water. Among the copepods the small cyclopoid *Tropocyclops prasinus*, in contrast to the larger *Cyclops bicuspidatus*, was two to three times as abundant in the upper 8 m. *Eurytemora affinis* adults and immatures appear to have been limited to the upper stratum.

The four *Diaptomus* species are of particular interest, for the coexistence

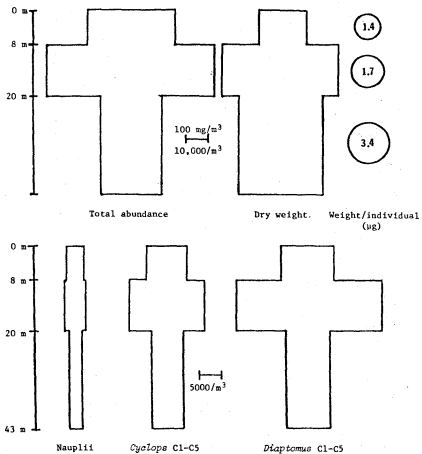


FIGURE 31. Vertical distribution of total zooplankton abundance, dry weight, and weight per individual (upper); vertical distribution of immature copepods (lower) at station DC-6, 1455 hrs, 23 August 1973.

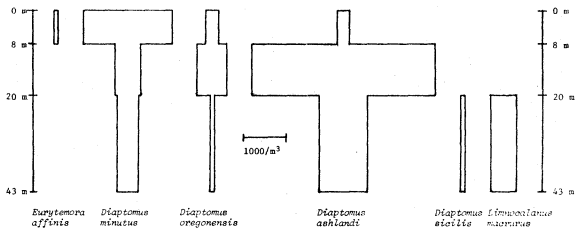


FIGURE 32. Vertical distribution of six calanoid copepod species at station DC-6, 1455 hrs, 23 August 1973.

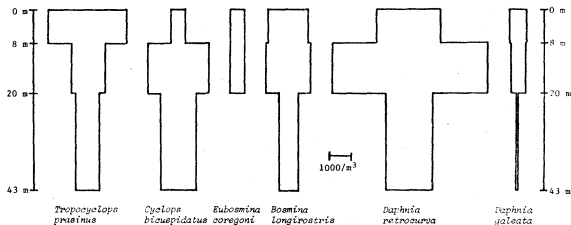


FIGURE 33. Vertical distribution of two cyclopoid copepod species and four cladoceran species at station DC-6, 1415 hrs, 23 August 1973.

of congeneric species is thought to imply a distinct separation of niches. Vertical distribution provides one way in which they may divide the environment, others being differences in size, feeding habits, season of maximum abundance, and season of reproduction. Investigators of other lakes (Rigler and Langford 1967; Langford 1938; Patalas 1969; Carter 1969; Wilson and Roff 1973) have generally found *Diaptomus minutus* to be most abundant near the surface. *Diaptomus oregonensis* is normally found at a greater mean depth, but there is considerable overlap of the two species. When they occur in the same lakes, *D. ashlandi* and *D. sicilis* usually have a deeper distribution. Wells (1960), reporting on Lake Michigan, concluded that all four species were most abundant in the epilimnion with *D. minutus* showing the strongest preference for the upper layers and *D. ashlandi* the weakest. Thus the distributions of the *Diaptomus* species shown in Figure 32, with a descending order of *D. minutus*, *D. oregonensis*, *D. ashlandi*, and *D. sicilis*, are consistent with the reported behavior of these organisms.

There is a definite trend for smaller species (*Tropocyclops*, *D. minutus*, *Bosmina*, *Asplanchna*) to favor the upper layers and for larger species (*Cyclops*, the other *Diaptomus* species, *Daphnia*, *Limnocalanus*) to favor the middle or lower parts of the water column. This is evident when biomasses are divided by numbers to calculate an average dry weight per animal. Average weights were 1.4 micrograms in the first 8 m, 1.7 micrograms in the next 12 m, and 3.4 micrograms in the bottom 23 m.

It is worth noting that, while the species were usually more concentrated in one of the depth intervals, most could be found in quantity in all three zones. Neither the surface layer nor the hypolimnion were empty of zooplankton.

NATURAL HISTORY

In this section we summarize information about the Cook area species of zooplankton that we have accumulated over nearly four years of biological surveys. For each major species, abundance data from this and past years are presented graphically for each of three depth zones. Plotted are the means of abundance at all stations within each zone plus or minus one standard deviation of the mean. For species of *Cyclops*, *Diaptomus*, and *Daphnia*, we have plotted abundance at the stations where specific identifications were made--DC-2, DC-5 and DC-6. In this case error bars enclose plus or minus one standard deviation of the mean of sample replicates. Data from 1970 is omitted when it is not directly comparable either because of different net mesh size or because of differences in sorting methods.

A representative number of immature copepods from 1973 samples were separated by instar with the aid of the descriptions of *Cyclops strenuus* contained in Gurney (1933), of *Diaptomus* species in Czaika and Robertson (1968) of *Epischura lacustris* in Main (1961), of *Eurytemora hirundinoides* in Davis (1943), and of *Limnocalanus grimaldii* in Lindquist (1959). Our usual procedure was to stage either all or the first 50 immatures encountered in a selected subsample.

COPEPODS

Copepod nauplii (Fig. 34). Our nets probably retain about half of these smallest stages of immature copepods. Calanoid nauplii, being larger, are more representatively collected than are cyclopoid nauplii. With the exception of *Limnocalanus*, nauplii of the several copepod species in Lake Michigan are not readily separable. Collectively they are found in lowest numbers during the winter months. Increases are seen through the spring, with the largest increases near the shore. Maxima of more than 20,000/m³ occur in July and August and are

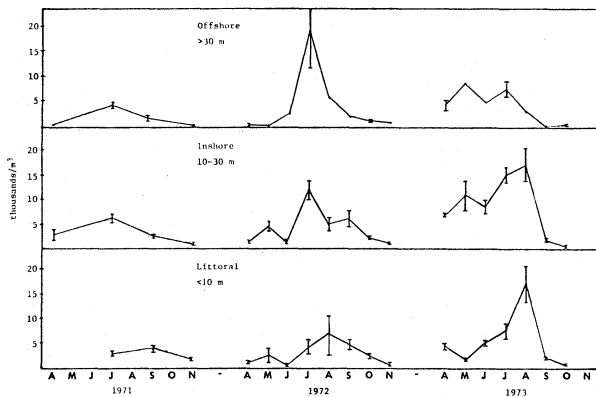


FIGURE 34. Seasonal distribution of copepod nauplii abundance in three depth zones.

followed by low numbers in the fall months. A similar pattern was reported by Johnson (1972) in southernmost Lake Michigan and by Heberger (1973) in Lake Erie. Numbers of nauplii may be expected to reflect rates of copepod egg production.

Cyclops bicuspidatus thomasi (Figs. 35 and 36). *Cyclops* is a raptorial feeder whose adults and late instar immatures prey heavily upon rotifers and nauplii (McQueen 1969), less commonly upon immature diaptomid copepodids. On a yearly basis, this is the most important zooplankton species in Lake Michigan and throughout most of the Great Lakes (Patalas 1972; Gannon 1972). In the 45 lakes studied in the experimental lakes area of northwest Ontario, presence of *C. bicuspidatus* was highly correlated with large, deep, transparent waters, and the species seldom appeared in shallow lakes (Patalas 1971b). It apparently does well in cold water, for winter population maxima are often reported and there is little regularity in published patterns of seasonal abundance.

In the Cook area, we find largest numbers of both adults and immatures in the midsummer months of July and August. During the winter, *Cyclops* are numerically fewer but make up a larger percentage of the fauna--up to 50%. Adults increased their numbers over both the winters of 1972 and 1973, while immatures became relatively scarce. This would seem to indicate low reproductive rates during these months. Egg-carrying females were found in samples from every month, but the highest percentages were seen in July.

Figure 37 diagrams the abundance of each *Cyclops bicuspidatus* instar at two stations in 1973. Results from a third station, intermediate in depth, have been inserted for the months of the major surveys. During April and May, C1 and C2 copepods outnumber other immature instars; reproductive rates are increasing. Early instars continue to predominate at the inshore station

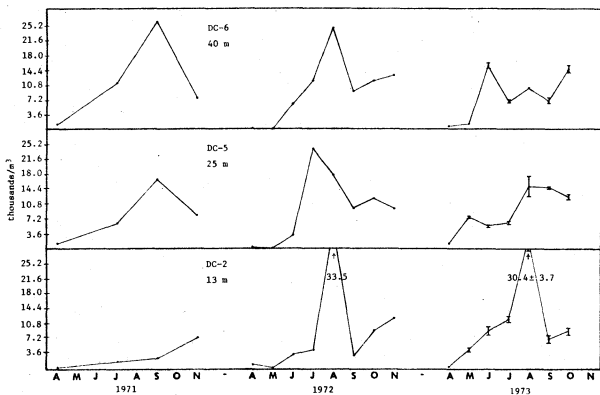


FIGURE 35. Seasonal distribution of *Cyclops* Cl-C5 abundance at three stations.

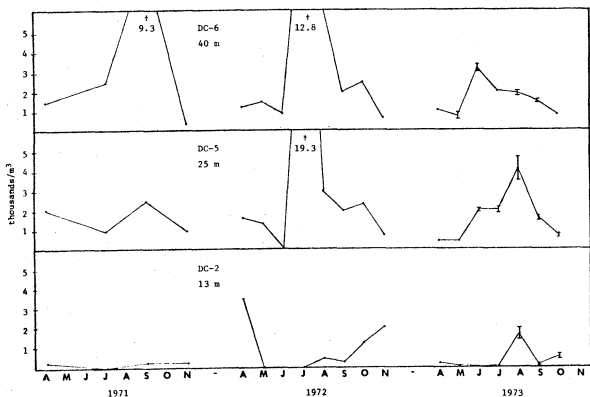


FIGURE 36. Seasonal distribution of *Cyclops bicuspidatus* abundance at three stations.

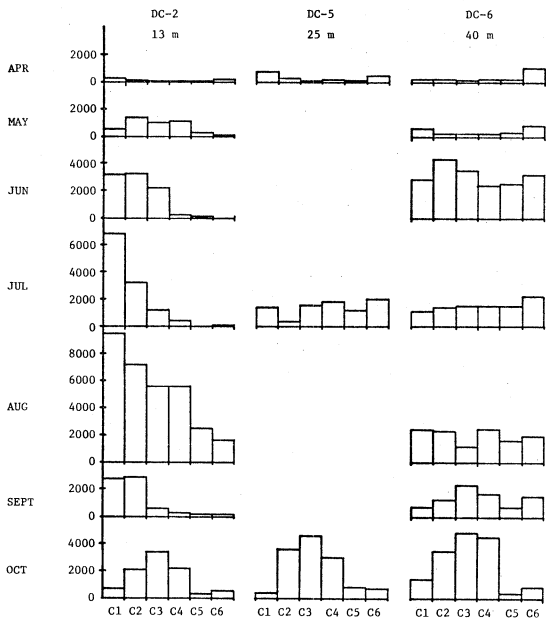


FIGURE 37. Abundance in #/m³ of *Cyclops bicuspidatus thomasi* copepodid instars at 3 stations on 3 dates and at 2 stations on all survey dates in 1973.

throughout the summer, but C3, C4, and C5 copepods are as numerous as C1 and C2 at the offshore station. We suspect that progressively larger immatures occupy progressively deeper positions in the water column until, like adults (C6), they are most concentrated offshore. In October, late instars outnumbered early instars both inshore and offshore, implying that egg production and/or nauplii survivorship had fallen off. If an equal amount of time was spent in each instar, one would have to infer from Figure 37 that copepodid mortality is very low or nonexistent. The more likely explanation is that much less time is spent in passage through the earlier instars.

Cyclops bicuspidatus adults are likely to be evenly distributed in the water column during spring and fall circulation and concentrated near the thermocline during the summer (Carter 1969; Wilson and Roff 1973).

Cyclopoids sometimes enter diapause in late summer, but none of the encysted copepods we have examined from the Cook area sediments have been *Cyclops bicuspidatus*. Females of this species usually outnumber males in all months of the year. We obtained male:female ratios of 49:51 in 1973 (n = 1588), 39:61 in 1972 (n = 4489), and 40:60 in 1970-71 (n = 1991).

Cyclops vernalis. We find this cyclopoid in only small numbers within the Cook area. It is most likely to be encountered inshore during the summer months. In the Great Lakes, *C. vernalis* is common only in the western basin of Lake Erie (Patalas 1972) and in Green Bay (Gannon 1972). Carter (1969) found it in Parry Sound during the warm months only, and Heberger (1973) characterized it as a littoral species in central Lake Erie.

Eucyclops agilis and *Paracyclops fimbriatus poppei*. Benthic habits prevent these species from appearing other than rarely in our plankton samples. They are probably uncommon in the Cook area.

Mesocyclops edax. This species is characteristic of small lakes and ponds where it is generally an aestival species. In the Great Lakes it is common only in Lake Erie (Davis 1969; Patalas 1972; Heberger 1973) and in Green Bay (Gannon 1972). It is believed to have been of greater importance in the Lake Michigan zooplankton before the establishment of alewife as the dominant planktivores (Wells 1970). *Mesocyclops* has remained exceedingly rare throughout the period in which we have sampled the Cook area.

Tropocyclops prasinus mexicanus (Fig. 38). This species and its European variant usually inhabit small lakes and ponds (Gurney 1933; Rylov 1963; Patalas 1971b). Its success in the Great Lakes is thus somewhat of a mystery. In Parry Sound and in Shawanaga Inlet of Georgian Bay it was found to be least abundant in the spring, common by midsummer, and an important constituent of the fall zooplankton (Carter 1969, 1972). Results obtained from Lake Ontario by Patalas (1969) indicate a preference for warm water and a fall peak in abundance. Johnson (1972) did not find *Tropocyclops* in Indiana waters of Lake Michigan until July. He reports an October maximum.

In the Cook area, *Tropocyclops* overwinters in very low numbers and increases its population slowly during the early summer. Not until July does it reach $100/m^3$. Peak numbers are found in August and September, and populations remain above $700/m^3$ into November. The percentage of ovigerous females is highest in July; immatures are not sampled quantitatively but appear to be most numerous in August.

We found greatest densities of this species in the uppermost water layers, as did Carter (1969), Patalas (1969) and Wilson and Roff (1973). We do not see the preponderance of females reported by Carter, but females of this species do outnumber males. Ratios were 39:61 in 1973 ($n = 520$), 48:52 in 1972 ($n = 646$),

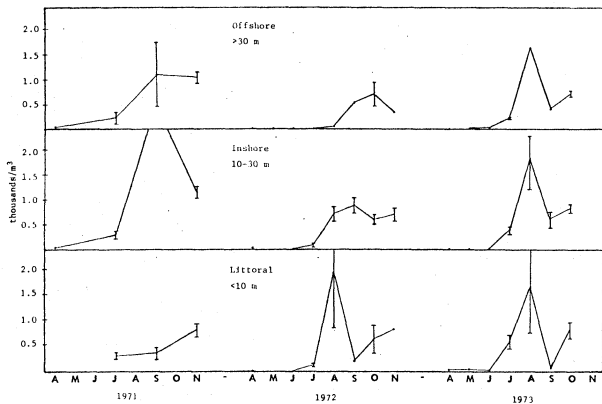


FIGURE 38. Seasonal distribution of *Tropocyclops* abundance in three depth zones.

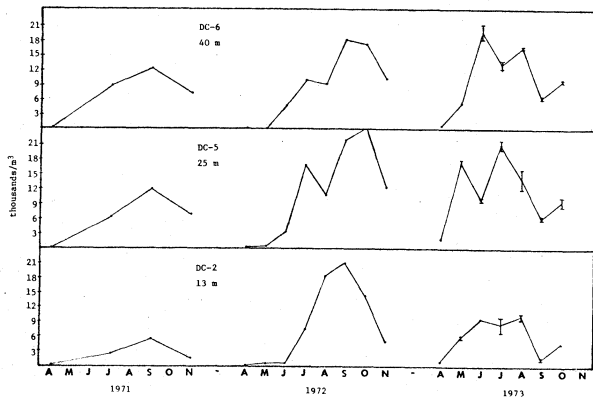


FIGURE 39. Seasonal distribution of *Diaptomus* C1-C5 abundance at three stations.

and 38:62 in 1970-71 ($n = 602$). Only in October 1972 did males exceed females.

Diaptomus spp. C1-C5 (Fig. 39). Separation of immature diaptomids by species is difficult in the Great Lakes where up to four species can be present, and it has yet to be undertaken. On the basis of gross morphology, a mixture of copepodids of all species appears to be present throughout the year, with the smaller immatures of *D. ashlandi* and *D. minutus* most numerous in the spring months and immature copepodids of *D. oregonensis* and *D. sicilis* making up a larger portion of the grouping in the early fall. Gannon (1972) did not find immature diaptomids until June at his offshore Lake Michigan station. He found highest densities in the July to September period, as did Johnson (1972) in southern Lake Michigan. This is the period in which we find the most *Diaptomus* immatures in the Cook area ($10-20,000/m^3$). We also find these stages in the winter and early spring, but numbers are always less than $1000/m^3$.

Diaptomus immatures are less abundant inshore than offshore, but differences are less pronounced than with adults. Figure 40 presents the results of an instar analysis of this group and shows an overall pattern resembling that of *Cyclops* C1-C5. In April and May early instars predominate; during the summer fewer late instars are captured inshore than offshore, and in the fall the most abundant stages are C4 and C5 copepodids. Again it may be inferred that reproduction accelerates in the spring and declines in the fall, that later instars occupy progressively deeper positions in the water column, and that development is most rapid during the early stages.

Diaptomus ashlandi (Fig. 41). Whittaker and Fairbanks (1958) found this species only in the open waters of oligotrophic lakes. It was not seen by Patalas (1971b) in the Experimental Lakes Area of northwest Ontario, and occurred in only one of the 100 southern Ontario lakes sampled by Rigler and

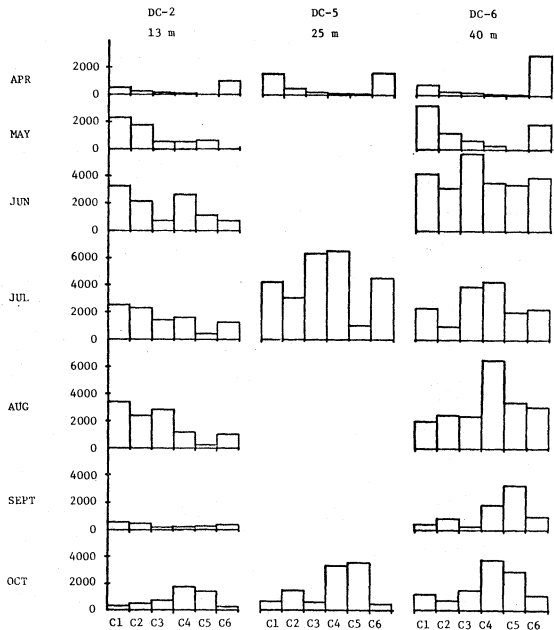


FIGURE 40. Abundance in $\#/m^3$ of *Diaptomus* copepodid instars at 3 stations on 3 dates and at 2 stations on all survey dates in 1973.

Langford (1967). In the Great Lakes, *D. ashlandi* is absent from Lake Ontario (Robertson 1966; Patalas 1969) and scarce in Green Bay (Gannon 1972). It does well elsewhere, and in Lake Michigan it is the dominant calanoid copepod.

Highest numbers of this species are often recorded in the summer, but winter populations are nearly as large, making it a particularly important species at that time of year. Gannon found low numbers only during October and November of 1969, the time of year in which lowest populations are found in the Cook area. In winter, spring, and summer, offshore abundance remains above 1000/m³. Inshore, *D. ashlandi* exceeded 500/m³ only on the three April survey dates and on the August 1973 date (when upwelling occurred). The species is probably concentrated in the metalimnion during the months of stratification, distributed throughout the column during times of complete mixing.

Davis (1961) found more ovigerous *D. ashlandi* in April than in other months. In the Cook area, this species reproduces throughout the year, but we see the most signs of reproductive activity in April. About one-third of the *D. ashlandi* females carry spermatophores at this time. Largest percentages of egg-bearing females are seen in May, and lowest percentages occur in late fall. Males are usually slightly more numerous--ratios of males to females were 54:46 in 1973 (n = 1652), 52:48 in 1972 (n = 3122), and 61:39 in 1970-71 (n = 1077).

Diaptomus minutus (Fig. 42). This species is a frequent inhabitant of small lakes, but in the Experimental Lakes Area it was more likely to dominate in the transparent waters of deeper lakes (Patalas 1971b). In the Great Lakes, it is most abundant in Lake Huron (Patalas 1972) and in Lake Michigan exclusive of Green Bay (Gannon 1972). Like *D. ashlandi*, *D. minutus* was present at Gannon's offshore station in substantial numbers during all months but October and November. Largest catches of this species (1000/m³) have occurred during the summer

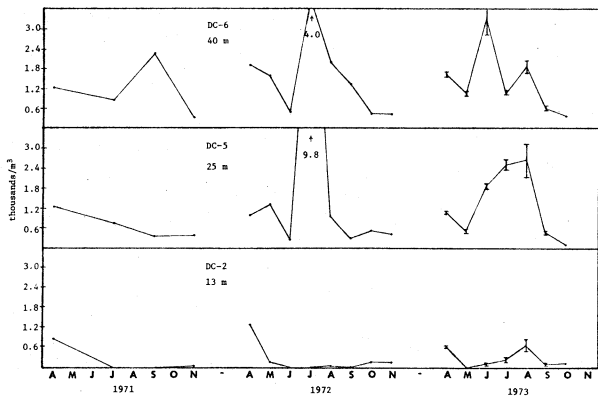


FIGURE 41. Seasonal distribution of *Diaptomus ashlandi* abundance at three stations.

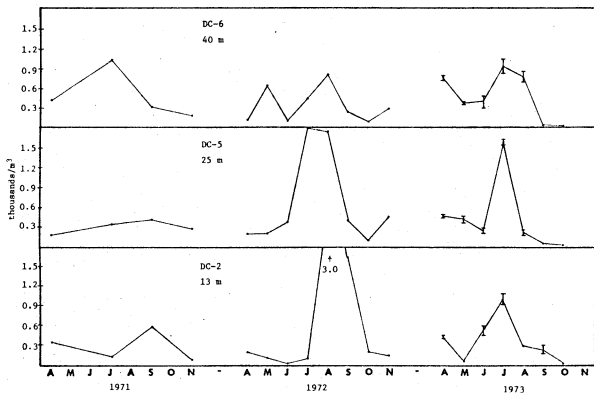


FIGURE 42. Seasonal distribution of *Diaptomus minutus* abundance at three stations.

months in the Cook area, while the smallest catches took place in the fall. A second minimum appears to occur in June, perhaps because overwintering adults die before maturation of spring cohorts. *Diaptomus minutus* is often as abundant inshore as offshore, a probable consequence of its pronounced preference for the upper water layers. Such a preference has been reported by Langford (1938), Wells (1960), Rigler and Langford (1967), Patalas (1969), Carter (1969), and Wilson and Roff (1973).

Davis (1961) listed March, April, and May as the months of maximum reproduction in Lake Erie. We have found reproductive females of this species in all but the winter months, with egg production highest during the period April to August. Sex ratios have seldom varied from equality, being 49:51 in 1973 ($n = 736$), 50:50 in 1972 ($n = 1001$), and 49:51 in 1970-71 ($n = 586$).

Diaptomus oregonensis (Fig. 43). Smaller lakes frequently contain this copepod, as do the warmer, more southerly portions of the Great Lakes (Robertson 1966). It is the most common diaptomid in the central and eastern basins of Lake Erie (Davis 1969) and in Green Bay (Gannon 1972). In the Experimental Lakes Area of Ontario, it was not found in deep or transparent lakes (Patalas 1971b).

Reports vary as to the month in which *D. oregonensis* is most abundant, the species usually being persistent throughout the year. Gannon did not find any definite peak in Lake Michigan. In the Cook area, we have noticed a trend for *D. oregonensis* to appear in larger numbers in the late fall. A moderate quantity of ovigerous females have been found in all survey months but June and November; reproductive individuals have not been seen in winter samples. *Diaptomus oregonensis* is known to produce resting eggs (Cooley 1971).

The species is usually more abundant offshore, where it occupies the upper

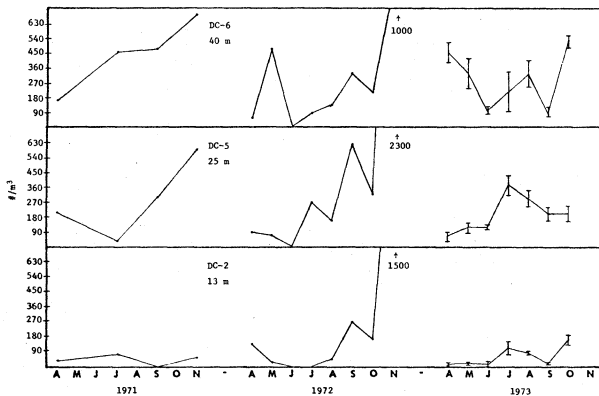


FIGURE 43. Seasonal distribution of *Diaptomus oregonensis* abundance at three stations.

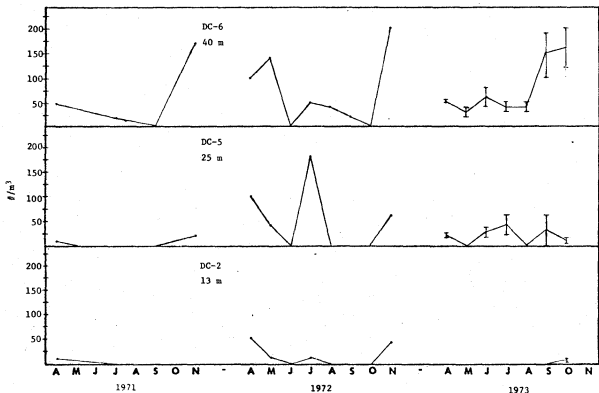


FIGURE 44. Seasonal distribution of *Diaptomus sicilis* abundance at three stations.

and middle water layers. Langford (1938) reported immatures of *D. oregonensis* to inhabit the hypolimnion in Lake Nipissing and move into the epilimnion as they matured.

We almost always find fewer males than females. Ratios were 35:65 in 1973 (n = 482), 41:59 in 1972 (n = 844), and 45:55 in 1970-71 (n = 100)

Diaptomus reighardi. A single individual of this pond form was found in the Cook area in 1972.

Diaptomus sicilis (Fig. 44). In the Great Lakes region, this diaptomid is most commonly associated with large deep bodies of waters. Patalas (1971a) found it making up 81% of the summer plankton in Great Bear Lake, 45% in Lake Superior, 13% in Lake Huron, and to be unimportant in Lakes Erie and Ontario. In Lake Michigan it seldom exceeded 100/m³ during the year of Gannon's 1972 study, and it was absent from Green Bay. Cold water seems to be the chief requisite to its success, for it can be found in smaller, more eutrophic lakes where it occupies the lower part of the water column (Rigler and Langford 1967). Wilson and Roff (1973) have also demonstrated this behavior in Lake Ontario. Great Lakes investigations conducted in shallow water (Davis 1954; Carter 1972; Johnson 1972; this study) report largest numbers of *D. sicilis* during the winter months.

Winter breeding was noted by Davis (1961) and inferred by Wells (1960). This is in conformity with our findings. Reproductive individuals are most common during the period November to May, although a few ovigerous females were found in Cook survey samples of June and July 1973. Sex ratios favored females 41:59 in 1973 (n = 135), were an even 50:50 in 1972 (n = 164), and favored females 43:57 in 1970-71 (n = 58).

Epischura lacustris (Fig. 45). This large calanoid is found throughout the Great Lakes and in numerous smaller lakes, but because it is not greatly abundant, little information about its ecology has been added by most studies. It seems to be a summer and fall species that is most characteristic of deep transparent lakes. *Epischura lacustris* was the subject of an intensive natural history investigation by Main (1961), and most of our knowledge comes from his work. In Whitmore Lake, Michigan, Main found two generations of *Epischura*, one hatching from resting eggs in the spring and maturing in the summer, and a second hatching from summer eggs produced by the first generation and maturing in the fall. Whether there are two generations in Lake Michigan cannot be determined from our data, but the production of fall resting eggs is a likelihood. Gannon (1972) found *Epischura* at his Lake Michigan station only during the period July to November, and *Epischura* are also absent from the Cook area during the winter and spring months. Adults first appear in midsummer and do not become common until the fall when they reach 150 or more per cubic meter both inshore and offshore. Immatures are also most numerous at this time, as are spermatophore-bearing females.

Eurytemora affinis (Fig. 46). This brackish water copepod entered the Great Lakes and became well established 10 to 15 years ago. It is not found in smaller lakes, nor is it ever reported as a dominant species in the Great Lakes. Association of *Eurytemora* with warm water is a conclusion shared by several studies. Carter (1969) describes the species as common to the coastal shallows of Parry Sound. Wells (1970) noted a preference for the surface waters of Lake Michigan, with a population maximum in July. Patalas (1969) investigating Lake Ontario, Gannon (1972) and Johnson (1972) investigating Lake Michigan, all found greatest densities of *Eurytemora* in the month of August. When Gannon sampled

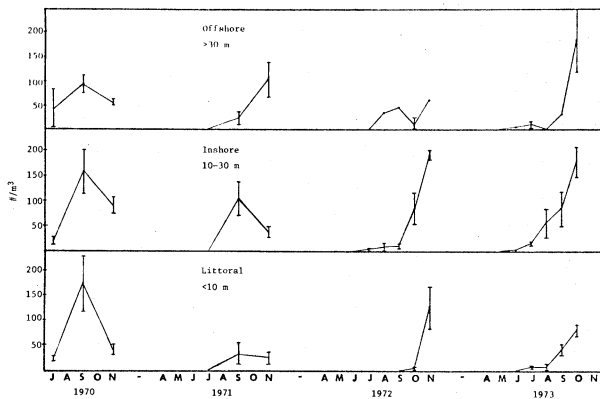


FIGURE 45. Seasonal distribution of *Epischura* abundance in three depth zones.

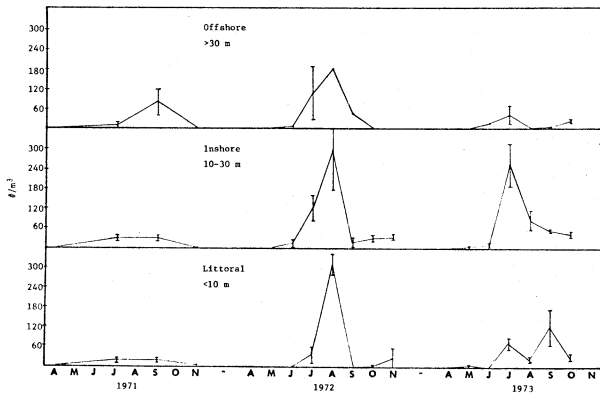


FIGURE 46. Seasonal distribution of *Eurytemora* abundance in three depth zones.

surface waters in transects across Lake Michigan, *Eurytemora* was consistently more abundant near shore. *Eurytemora affinis* was the only calanoid copepod he found in the littoral zone of Green Bay.

The Cook surveys also yielded largest numbers of *Eurytemora* in July and August (100-300/m³). Immatures appear as early as April, presumably hatching from resting eggs, but adults are not normally seen before June. Densities are highest at inshore and littoral zone stations. As diagramed in Figure 47, immatures found in the spring months of 1973 were predominantly C1 and C2 copepodids. From July onwards, all instars were found in nearly equal relative abundance. At the time of the July peak, numbers of immatures were much higher close to shore. Highest percentages of ovigerous females were seen in July. Sex ratios favored males in July; data from other months are limited but have been averaged with July data to produce yearly male:female ratios of 58:42 in 1973 (n = 556), 51:49 in 1972 (n = 94), and 64:36 in 1970-71 (n = 44).

Limnocalanus macrurus (Fig. 48). A wealth of evidence supports the notion that this glacial relict is a cold-water stenotherm restricted to the hypolimnion and present only in large, deep, northern lakes (Langford 1938; Wells 1960; Rigler and Langford 1966; Carter 1969; Patalas 1969, 1971b, and 1972). It is nearly absent from Lake Erie (Robertson 1966; Davis 1969), absent from all but the northernmost part of Green Bay (Gannon 1972), and was not seen during the months of Johnson's (1972) study of southern Lake Michigan.

Carter's publication includes a life history of this organism in Parry Sound, Georgian Bay. Only one generation was produced per year, with breeding during the period October to December. The first new-generation adults appeared in March, and from May to November the majority of the copepodids were C6 (adult). Carter found that successively larger stages occupied greater depths

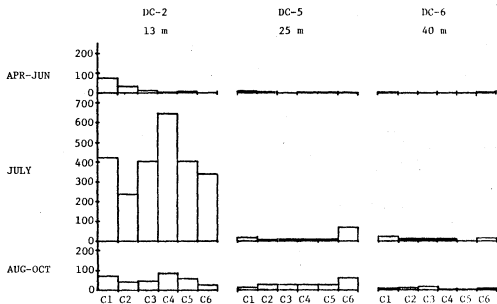


FIGURE 47. Abundance in $\#/m^3$ of *Eurytemora* copepodid instars at three stations in July and mean abundances on dates preceding and following the July survey.

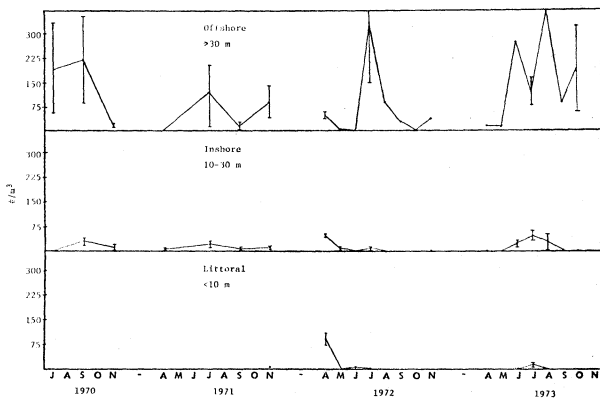


FIGURE 48. Seasonal distribution of *Limnocalanus* abundance in three depth zones.

and that all moved down in the water column with warming of the lake. Similar depth distributions occur in Lake Ontario, according to Wilson and Roff (1973). In Lake Michigan, Gannon (1972) found spermatophore-bearing females in the winter and copepodids 4 and 5 in April. He saw *Limnocalanus* in Milwaukee Harbor only during the winter.

In the Cook area, *Limnocalanus* were collected in winter entrainment samples, but during the April to November period of field surveys they were collected in number only at stations in the offshore zone. One exception was the survey of April 1972, a survey taken before water temperatures had reached 4°C. In the offshore zone, numbers are low in April and May--a period during which the last old-generation individuals disappeared. From July to November, fluctuations probably reflect position of the thermocline, with lowest numbers being caught when the thermocline is deepest.

Figure 49 illustrates abundance by instar for those 1973 survey months during which immatures were present in the Cook area. A single generation per year is evident, with winter breeding and spring maturation. On all survey months, the inshore waters contained fewer *Limnocalanus* immatures, and these were almost exclusively nauplii and C1-C3 copepodids. Early instars predominated at all stations in April; in May the later instars were equally abundant while numbers of nauplii and C1 copepodids had decreased. By June only C4, C5, and adult copepodids could be found, leaving the inshore region empty of *Limnocalanus*. A noticeable increase in the numbers of adults occurred. These adults were free of the epizoid protozoa which infest adults collected in April, so we assume they were newly-molted individuals. In July the population consisted almost entirely of adults, and immature *Limnocalanus* were not seen from August to October. In 1972, *Limnocalanus* nauplii were collected in October, indicating the onset of breeding, but no nauplii had appeared by the October 1973 date.

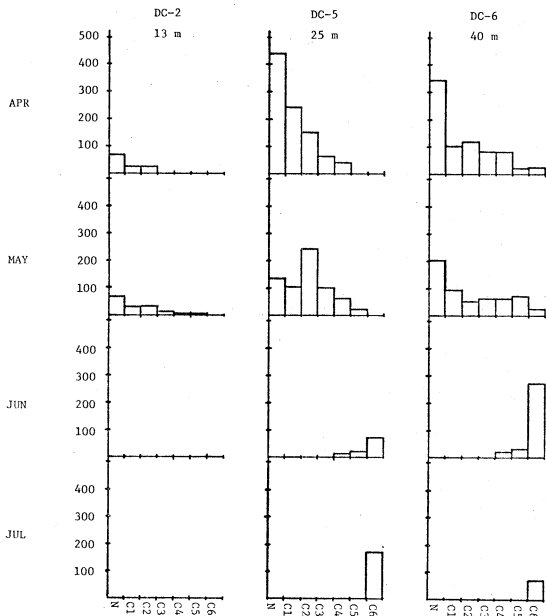


FIGURE 49. Abundance in $\#/m^3$ of *Limnocalanus* nauplii and copepodid instars at three stations on four dates in 1973.

Spermatophore-bearing females were found in winter entrainment samples.

Nearly equal proportions of the sexes have been counted between 1970 and 1973, 47:53 (n = 216).

Senecella calanoides. This Lake Michigan species is effectively absent from our collections throughout the year. Its occurrence in the Great Lakes is restricted to regions of greater depths than the Cook area.

Canthocamptus sp. A harpacticoid copepod frequently collected by Gannon (1972) in Lake Michigan plankton was identified by M. S. Wilson as *Canthocamptus robertcookeri*. Our best taxonomic efforts assign the harpacticoid common in the Cook area to the species *Canthocamptus staphylinoides*. Harpacticoids are benthic, but *Canthocamptus* is often found in the upper water layers far from shore (Swain et al. 1970; Gannon 1972) so a partially planktonic role can be assumed. Females carrying eggs were collected from the Cook area in the winter and in April and May. Harpacticoid nauplii and immatures were common in the month of May. From July to November this organism is much less likely to enter the plankton and immatures or ovigerous females are rare. Encysted *Canthocamptus* can be found in sediments from the Cook area, but quantitative information about this interesting phenomenon is unavailable.

Bryocamptus sp. A second harpacticoid, rarely found, appears to belong to the *Bryocamptus hiemalis* group.

CLADOCERANS

Alona affinis. This large benthic cladoceran occurs in the littoral zone of the Cook area during midsummer. It often wanders off the bottom at night, but it has always been rare in daytime plankton samples.

Bosmina longirostris (Fig. 50). *Bosmina longirostris* is the most abundant crustacean in the summer zooplankton of the Great Lakes. While it has been suggested as an indicator of eutrophic conditions, conclusions based on its abundance are particularly venturesome because population sizes fluctuate rapidly. We believe that it is best thought of as an indicator of unstable conditions. *Bosmina* is found in all lake types and, in the Experimental Lakes Area, does not preferentially dominate any one type (Patalas 1971b). As early as July 1927, Eddy found 120,000 *Bosmina "longispina"* per cubic meter in Lake Michigan near Chicago. This number is comparable to the maxima reported by Johnson (1972) in July samples collected off Burns Ditch and Gary, Indiana, and to the July and August maxima that occur in the Cook area. Peaks also occur in July and August in Lake Ontario (Patalas 1969). *Bosmina* are more numerous in the upper water layers (Wells 1960; Patalas 1969; Wilson and Roff 1973), and within the surface waters they are more abundant near shore (Gannon 1972).

Bosmina seem to be adapted for rapid reproduction, making it possible for them to take advantage of periods in which food is plentiful. If they are less effective competitors than *Daphnia*, this may explain the rapid population declines which occur in late August when food is likely to become limiting. It may also explain why the inshore regions, which receive infusions of upwelled nutrient-rich waters, contain more irregularly fluctuating populations.

In each month of 1973, we measured the length to the nearest 25 μ of 200 or more *Bosmina* from samples collected at stations DC-2, DC-5 and DC-6. Lengths were measured with the ocular micrometer of a dissecting microscope at a magnification of 98 diameters. Length frequencies changed from month to month but varied little between inshore and offshore, hence we combined the measurements for each month to produce Figure 51. Rammer (1926) found four instars in European populations of *Bosmina longirostris*, the last two of which were

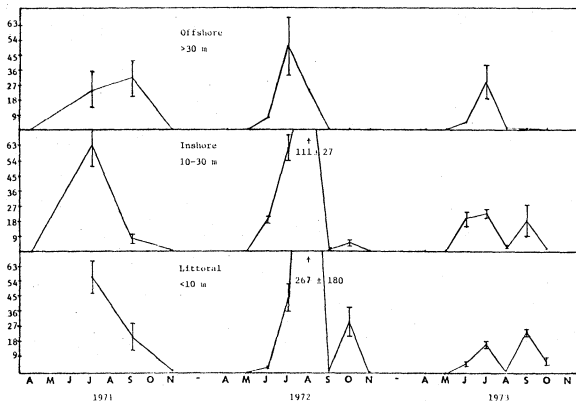


FIGURE 50. Seasonal distribution of *Boarina* abundance in three depth zones.

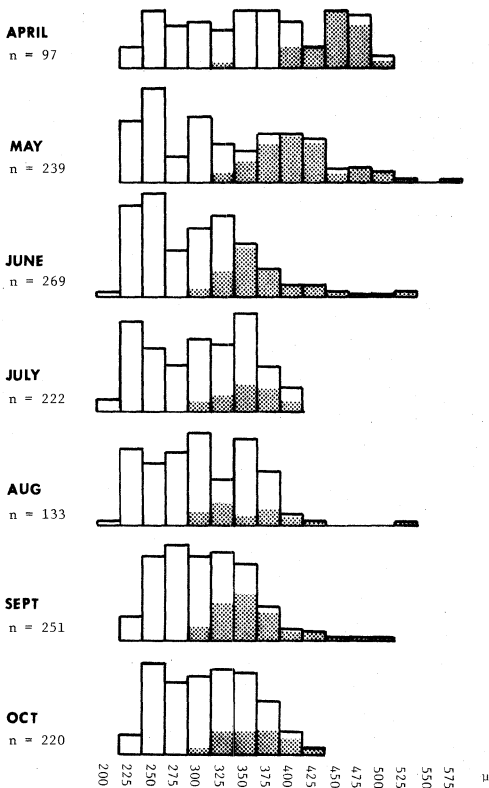


FIGURE 51. Length frequency of *Bosmina longirostris* collected in the Cook survey area of Lake Michigan in 1973. Stippled portions of bars indicate frequency of gravid individuals.

reproductive. Since the ranges in lengths exhibited by each instar overlap those of other instars, cladocerans cannot be staged confidently by means of their length. If Rammer's data are applicable to Lake Michigan *Bosmina*, then those individuals measuring 250 μ or less may be assigned to the first instar and those bearing eggs (the stippled portion of Fig. 51) may be assumed to have reached at least the third instar.

A size shift with increasing temperature is evident in the Cook area population. A majority of those individuals that may be associated with Rammer's first instar measured 250 μ in April, May and June and again in September and October. In July and August, 225 μ *Bosmina* were more frequent than 250 μ individuals. June, July, and August were the only months in which 200 μ individuals were found. Frequency of large individuals declined from April, when about 35% of all *Bosmina* measured 400 μ or more, to July, when less than 5% attained this length. It may be supposed that the April population contained large numbers of older, overwintering individuals. High percentages of those *Bosmina* measuring 325 μ or more were gravid during April, May and June when the population was increasing in size. At the time of maximum numbers, July, a decline in the percentage of gravid *Bosmina* was evident. This was followed by a sharp decrease in the size of the population.

A small number of males and ehippial females are found in the Cook area in July and again in October, but not until November do they make up 10% of the *Bosmina* populations.

Chydorus sphaericus (Fig. 52). *Chydorus* is a littoral organism which often enters the limnetic zone of small lakes in the autumn. It has been associated with eutrophic conditions. In the Great Lakes it is usually listed as an unimportant member of the summer and fall faunas. Two exceptions are Cannon's 1972

finding of 8-15,000 individuals per cubic meter in the September plankton of Green Bay and Heberger's 1973 report of 30,000 Chydoridae/m³ in the inshore September plankton of Lake Erie. Highest abundances reported from the open waters of Lake Michigan are the 470/m³ found by Johnson (1972) at the southern end of the lake.

In the Cook area, abundances in the inshore and littoral zone are distinctly higher than in the offshore region. Numerical maxima occur between July and September and seldom exceed 200/m³.

Ceriodaphnia quadrangula. *Ceriodaphnia* is a pond genus which only dominates the zooplankton of the smallest lakes. Some of the highest counts recorded in the Great Lakes are those of Johnson (1972) in the southern extreme of Lake Michigan--over 2000/m³. These were obtained in August, the same month in which our counts are generally largest (up to 400/m³). Ehippial females have been found in October samples from the Cook area.

Daphnia galeata mendotae (Fig. 53). This *Daphnia* is present in all lake types but more frequently in larger, deeper, more transparent water (Patalas 1971b). It is rare in Lake Ontario (Patalas 1969; Wilson and Roff 1973) and in the southern part of Green Bay (Gannon 1972), but it does well in Lake Erie (Patalas 1972; Davis 1969). In the Cook survey area of Lake Michigan, *D. galeata* reaches population levels greater than 1000/m³ both inshore and offshore in the fall. While occasional individuals can be found in the winter and through the spring, it does not appear regularly in samples until August--a month later than *D. retrocurva*. Peak numbers are likely to be in October, again one month later than *D. retrocurva*. In November, numbers of *D. galeata* equal or surpass those of *D. retrocurva*. Sexual reproduction begins in October when males appear, followed shortly by ehippial females. In the late fall, over 30% of the Cook

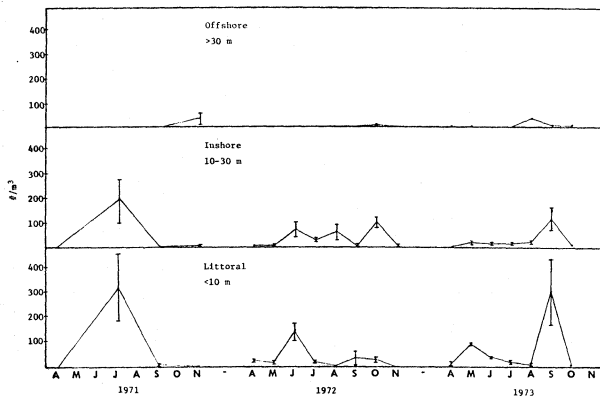


FIGURE 52. Seasonal distribution of *Chydorus* abundance in three depth zones.

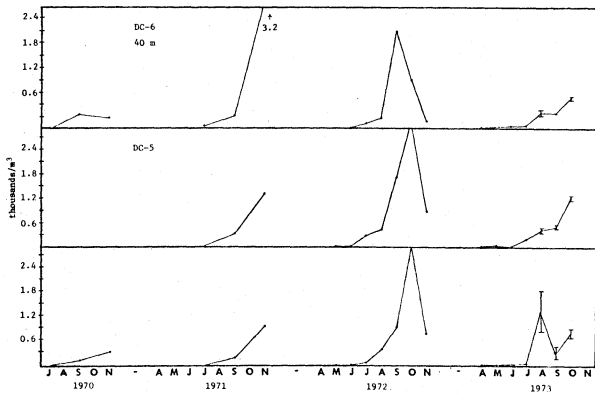


FIGURE 53. Seasonal distribution of *Daphnia galeata* abundance at three stations.

area population are males. *Daphnia galeata* appears to occupy a higher position in the water column than that of *D. retrocurva*.

Daphnia longiremis. *Daphnia longiremis* is a cold-water species whose southern limit is the Great Lakes region (Brooks 1957). Investigators have reported both winter population peaks and midsummer peaks in the hypolimnion. In the Great Lakes, *D. longiremis* has only been described as an uncommon offshore species. In the Cook area it is generally absent. More were found in winter entrainment samples than at other times of the year.

Daphnia retrocurva (Fig. 54). This species is an important late-summer component of the zooplankton in all of the Great Lakes but Superior. It can be found also in smaller lakes and is most likely to dominate in lakes of intermediate trophic state (Patalas 1971b). August and September were the months in which Patalas (1969) found largest numbers in Lake Ontario. Wells (1960), Gannon (1972), and Johnson (1972) observed a Lake Michigan pattern of appearance in July, rise to dominance in August and September and decline in the fall. This is also the seasonal distribution that recurs in the Cook area. Our maximal abundances of 8-15,000/m³ are smaller than those obtained by Johnson, and larger than those of Gannon. Only occasional individuals can be found in the spring, and they are usually immature, low-helmeted females. Summer and fall forms are tall helmeted but do not develop the strongly recurved shape seen in smaller lakes and in the western basin of Lake Erie. Small, immature *Daphnia* predominate in July and August. As the fall advances, modal size increases and males and ephippial females make their appearance. From 10 to 15% of the *Daphnia retrocurva* population are males in October and November.

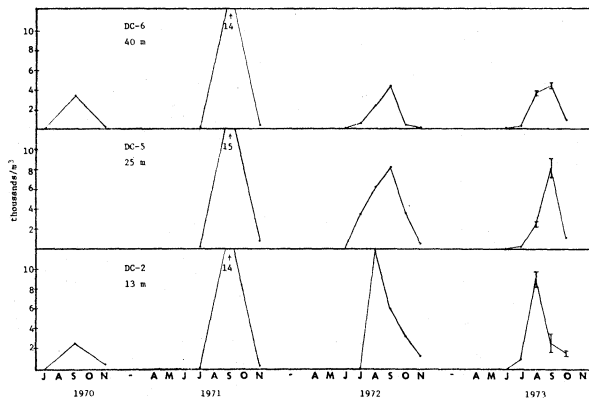


FIGURE 54. Seasonal distribution of *Daphnia retrocurva* abundance at three stations.

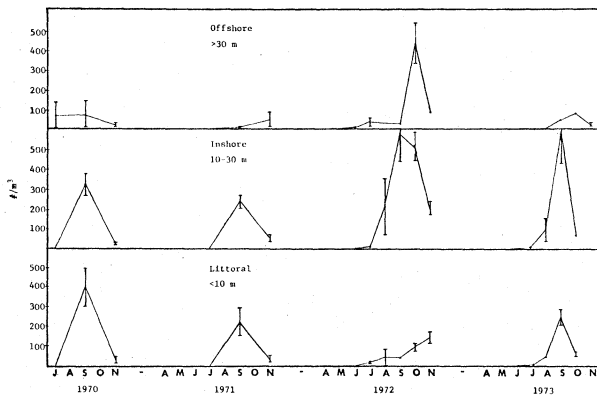


FIGURE 55. Seasonal distribution of *Diaphanosoma* abundance in three depth zones.

Diaphanisoma leuchtenbergianum (Fig. 55). *Diaphanosoma* often dominates the zooplankton of small bodies of water, but it plays only a minor role throughout the Great Lakes. In the Cook area it has always been rare or absent before August. Peak numbers occur in September and at this time males appear. As the water cools in the fall, populations decline rapidly to zero.

Eubosmina coregoni (Fig. 56) syn. *Bosmina coregoni coregoni*. In September 1969, Gannon (1972) found 1200 *Eubosmina* per cubic meter at his offshore Lake Michigan station and 5800/m³ in Milwaukee harbor. Patalas (1969) recorded August and September peaks in Lake Ontario. In the Cook area, this species does not become plentiful until September and does not reach maximum numbers (5,000/m³) until October and November. Thus only in the late fall does it equal or surpass *Bosmina longirostris* in importance.

Figure 57 contains length-frequency histograms for *Eubosmina* similar to that presented for *Bosmina*. Sufficient data were available only from those months in which *Eubosmina* is abundant. As the population size increased from August to October, higher frequencies of small individuals (early instars) were seen. The percentage of gravid individuals fell in October, the month in which populations probably peaked.

Cook survey samples contain male *Eubosmina* and ephippial females in October and November.

Eurycerus lamellatus. This large benthic cladoceran was not noticed in Lake Michigan until 1954 (Wells 1960), and its role in the limnetic plankton is generally considered minor. It has occasionally been reported by European workers to stray from the bottom at night (Frey 1971). Examination of our records for past July surveys reveals that *Eurycerus* is most likely to be encountered in plankton samples collected at stations between 10 m and 20 m in

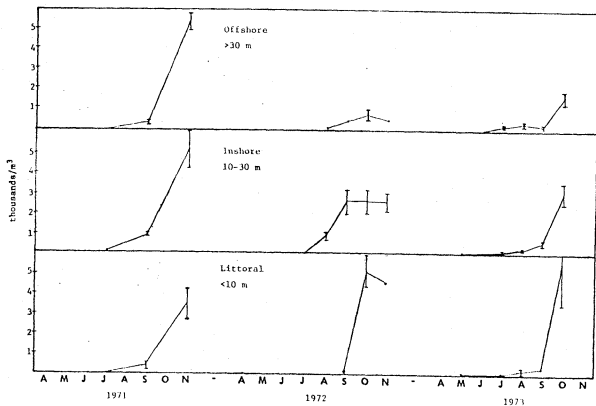


FIGURE 56. Seasonal distribution of *Eubosmina* abundance in three depth zones.

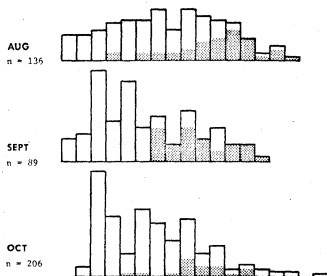


FIGURE 57. Length frequency of *Eubosmina coregoni* collected in the Cook survey area of Lake Michigan in 1973. Stippled portions of bars indicate frequency of gravid individuals.

depth. During the summer it is present in night plankton samples from the Cook area ($500/\text{m}^3$) but rare in daytime samples. Rhodes (1971), studying the food habits of alewife at the shallow southern end of Lake Michigan, found that *Eurycerus* made up 20% by volume of the stomach contents of fish caught in August and September.

Holopedium gibberum (Fig. 58). While *Holopedium* has been described as an indicator of oligotrophic soft waters (Piejler 1965), it dominated only those Experimental Lakes Area waters which were shallow and highly colored (Patalas 1971b), and it is often abundant in the comparatively hard waters of Lakes Huron and Michigan. Gannon (1972) found $250/\text{m}^3$ at an offshore Lake Michigan station in 1969 but very low numbers in Green Bay. In the Cook area, *Holopedium* is a fall species which sometimes produces blooms of $2\text{--}4,000/\text{m}^3$ in September (1971 and 1972) and in other years does not exceed $500/\text{m}^3$ (1970 and 1973). Males appear in the fall, with up to 25% of the population being male by November. Langford (1938) found this species to have a distinct preference for the upper water layers in Lake Nipissing.

Ilyocryptus sordidus, *Leydigia quadrangularis*, *Macrothrix laticornis*, *Pleuroxus denticulatus*. Seasonal dynamics of these benthic cladocerans are not known for the Cook area. They are rarely caught in plankton samples.

Latona setifera, *Scapholeberis kingi*, *Sida crystallina*. These littoral cladocerans are extremely rare in the region of the Cook plant.

Leptodora kindtii (Fig. 59). *Leptodora* is present throughout the Great Lakes, but methods designed to estimate populations of smaller, more numerous zooplankters often fail to provide information about this large predaceous cladoceran. Averaging of several stations from the Cook study area makes

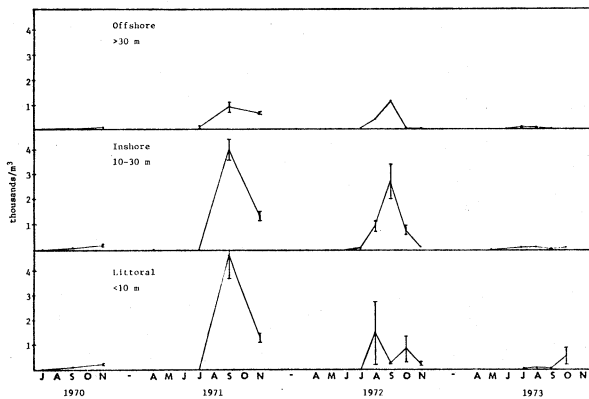


FIGURE 58. Seasonal distribution of *Holopedium* abundance in three depth zones.

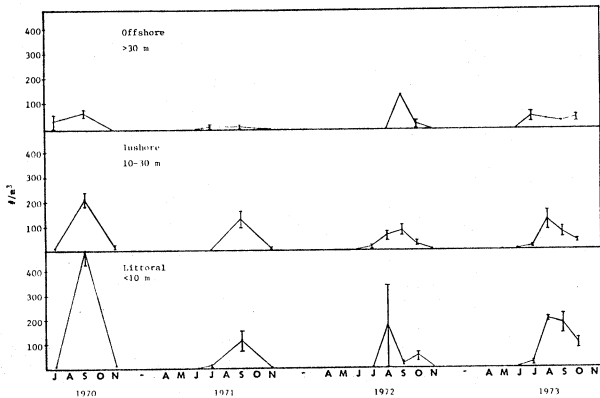


FIGURE 59. Seasonal distribution of *Leptodora* abundance in three depth zones.

visible a very regular seasonal pattern in southeastern Lake Michigan.

Leptodora are absent before July, increase to 100-200/m³ in August and September, and then decrease to near zero abundance by November. Timing coincides with the dominance of *Daphnia* and maximal numbers of several other large cladoceran species. *Leptodora* populations are largest in the littoral and inshore zones. Males appear in the autumn.

Polyphemus pediculus (Fig. 60). Little is known about the ecology and natural history of this predator. In the Great Lakes it is always reported as appearing in the plankton briefly and in small numbers. Patalas (1969) found it in Lake Ontario only in July and August. Gannon (1972) saw *Polyphemus* only in August samples from Lake Michigan. It is an aestival species in the Cook area, appearing suddenly in July, reaching peaks of 300-600/m³ and then disappearing in the fall. Abundances are higher inshore and in the littoral zone. Appearance of *Polyphemus* coincides with periods in which the zooplankton is dominated by small organisms--the cladoceran *Bosmina longirostris* and several rotifer species.

ROTIFERS

Quantitative information about all but the largest rotifer species, *Asplanchna priodonta*, is precluded by the mesh size of our nets. However, some qualitative observations can be made about the Cook area. In April and May the 1973 fauna was dominated by *Synchaeta* and by *Brachionus* spp., with noticeably larger numbers of rotifers in the warmer inshore waters. Standing crops and species richness were highest in June and July, with *Keratella quadrata* and the colonial *Conochilus unicornis* most conspicuous in our samples. Rotifer abundance appeared to decline greatly in August and remain low through

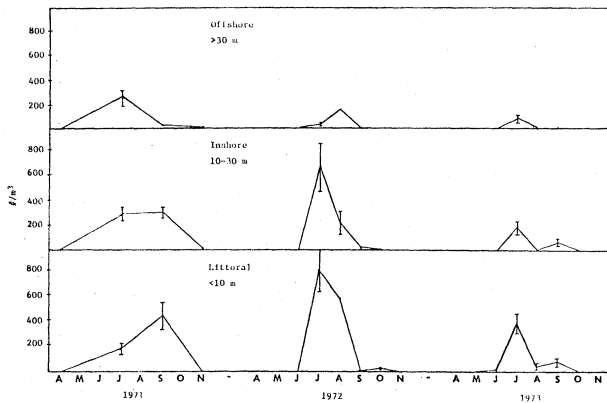


FIGURE 60. Seasonal distribution of *Polydora* abundance in three depth zones.

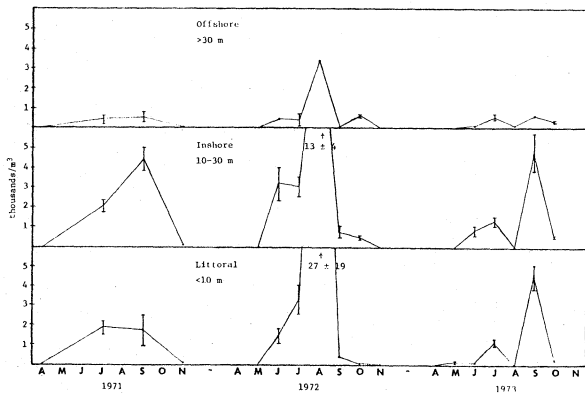


FIGURE 61. Seasonal distribution of *Asplanchna* abundance in three depth zones.

the fall. *Hellicottia longispina* was the only species found in every month; still another perennial species, *Keratella cochlearis*, occurred in all months but April. Less common species noted in the summer and fall months were *Pleosoma hudsoni*, *Filinia longiseta*, *Polyarthra* spp., *Trichocerca multisetis*, and, *Trichocerca longiseta*. A species of *Notholca* was present in the spring.

Asplanchna priodonta (Fig. 61). *Asplanchna* is a predator in whose gut one can often see other rotifer species or at times a *Bosmina*. It also engulfs larger algal and detrital particles, and these may be an equally important food source. In the Cook area, *Asplanchna* is most abundant in samples that contain abundant *Bosmina*, indicating that it, too, responds rapidly to conditions of plentiful food. Largest numbers (3-5,000/m³) are found inshore in July, August and September.

DIVERSITY

Seasonal patterns of zooplankton diversity in the Cook area are presented in Figures 62 and 63. Values plotted in Figure 62 were obtained using the information theory index $\bar{d} = -\sum p_i \log_2 (p_i)$, where p_i is the proportion of the samples made up by the i th species. This index quantifies the amount of uncertainty about the identity of an individual chosen randomly from the sample. Figure 63 is a plot of the number of species which make up 0.5% or more of the sample. In both cases the community was defined as all post-embryonic or post-naupliar crustaceans. Unidentified immature copepods were apportioned according to the relative abundance of adults in the sample.

Offshore, diversities were consistently higher, probably because a longer water column provides a greater range of habitat. Measured by either index, diversity is lowest in June and July when *Bosmina longirostris* may make up 50%

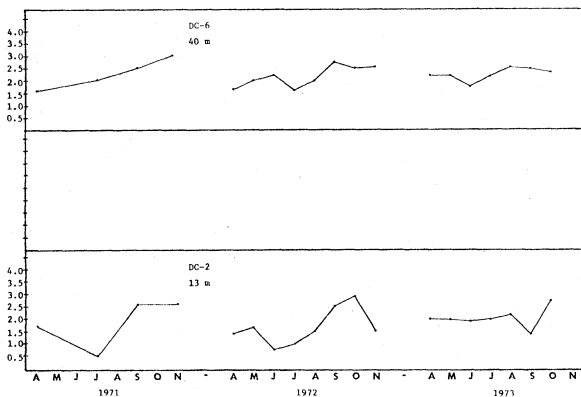


FIGURE 62. Seasonal distribution of zooplankton diversity at two stations: information theory index.

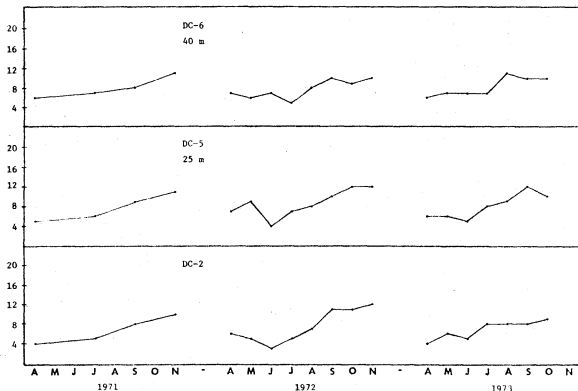


FIGURE 63. Seasonal distribution of zooplankton diversity at three stations: numbers of species comprising 0.5% or more of the assemblage.

of the fauna, highest in the fall when species richness is greatest. Differences between the two indices are most evident inshore where the information theory index, more sensitive to species evenness, drops sharply on dates when *Bosmina* is abundant.

SUMMARY

When results of this and past years of biological sampling in the area of the Cook nuclear facility are compared, one can see enough recurring features to construct a predictive description of the yearly zooplankton cycle. The cycle is subject to the vagaries of weather, upwelling, fish grazing, and phytoplankton succession as well as to less obvious long-term changes which may be occurring. Calculation of the magnitude of year-to-year variation will await completion of our preoperational studies.

In the winter six copepods are present, all of them in the inshore area where they are subject to entrainment. Two, *Limnocalanus macrurus* and *Diaptomus sicilis* are actively breeding, while the other four, *Cyclops bicuspidatus thomasi*, *Diaptomus ashlandi*, *D. minutus*, and *D. oregonensis* await spring phytoplankton blooms before beginning intensive egg production.

Beginning in mid-April, nearshore water temperatures exceed 4°C, and the warming is accompanied by increases in diatom densities, the appearance of larger numbers of copepod nauplii, and the arrival of spawning planktivorous fish. At this time, adults and larger immatures of the six copepod species become scarce inshore compared to their offshore abundance--a condition which persists through the summer and fall. Both zooplankton biomass (about 30 mg/m³) and total abundance (about 5000/m³) are at a yearly low at this time. In May, nauplii continue to increase and they begin to mature to copepodids. The

appearance and gradual increase in numbers of *Bosmina longirostris* and of several rotifer species is evident.

The lake becomes thermally stratified in June, and thereafter the surface layers warm rapidly. Zooplankton numbers increase sharply, with most of the increase being in immature copepods, in rotifers, and in the small cladoceran, *Bosmina longirostris*. *Bosmina* dominates June samples and reaches still more prodigious numbers in July and August. With thermal stratification and the calmer summer weather comes stratification of most zooplankton species within the water column. With some exceptions, the smaller species occupy the warmer upper layers. In July the predaceous cladoceran *Polyphemus pediculus* becomes abundant, as does the only calanoid showing a preference for the inshore region, *Eurytemora affinis*. In the summer months, a benthic cladoceran, *Eurycerus lamellatus*, becomes an important member of the shallow water plankton at night.

The effects of upwelling are most conspicuous in July and August. This, together with periodic storm-induced resuspension of sedimented material, probably accounts for the greater instability of the inshore plankton populations during these months. While sound evidence is not yet available, we hypothesize that the most immediate effect of upwelling on the zooplankton is a displacement of the warm-water species *Bosmina*, *Eurytemora*, *Polyphemus*, and *Asplanchna* and their replacement by such middle-depth organisms as *Cyclops bicuspidatus*, *Diaptomus ashlandi*, and *Daphnia retrocurva*.

Daphnia have appeared in moderate numbers by July, and in August and September they become the dominant cladocerans. In August there occurs what is probably a nutrient-related change in phytoplankton composition. Green and blue-green species form as much as 50% of what was in prior months an alldiatom flora. These changes may be responsible for at least some of the changes in zooplankton composition which occur between August and September.

Small organisms--*Boesmina*, rotifers, copepod nauplii--decline in number, and larger cladocerans--*Daphnia retrocurva*, *Daphnia galeata mendotae*, *Holopedium gibberum*, *Diaphanosoma leuchtenbergianum*, *Eubosmina coregoni*--reach their yearly maximum. The large predator *Leptodora kindtii* is most abundant in September. Zooplankton biomasses (about 200 mg/m³) and total abundances (about 100,000/m³) are greatest in late summer, remain high until September and then decrease.

As the water cools in the fall, cladoceran populations decrease. In October and November, males and ephippial eggs are produced. This is likely to be the principal means of winter survival, for by late January all cladoceran species are rare or absent. Copepod numbers decline more slowly, so that by November the zooplankton is again dominated by *Cyclops* and the species of *Diaptomus*. In addition, the fall fauna contains the small cyclopoid *Tropocyclops prasinus* and the calanoid *Epischura lacustris*.

A large percentage of the fall copepods are immature, but as the winter progresses these gradually mature until by late winter the community consists mostly of adults. The effect of a winter with extensive nearshore ice cover is not known.

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NATURAL LAKE WATER TEMPERATURES IN THE NEARSHORE
WATERS OF SOUTHEASTERN LAKE MICHIGAN

Erwin Seibel and John C. Ayers

Abstract. Three and one-half years of study of the lake water temperatures of southeastern Lake Michigan at four locations ranging from 2 feet to 40 feet of depth and at from 300 to 3375 feet from shore have produced the conclusion that the occurrence of natural lake water fluctuations of more than 3°F are a common event with the exception of the month of January. The greatest and most frequent daily temperature fluctuations occur during the months of June through September, with the observed maximum daily range of 27°F having occurred on 20 July 1970. Varying amounts of upwelling of colder deeper offshore waters can best explain these temperature fluctuations. Direct wind induced upwelling is thought responsible for the natural daily fluctuations in excess of 12°F while a combination of factors seems a plausible explanation for the smaller ranges. The range of the maximum and minimum recorded monthly temperatures was substantial, however, the average maximum and average minimum monthly temperatures at different depths did not fluctuate greatly from year to year. The deeper stations consistently showed higher maximum and minimum average temperatures for the months of January through March, while the shallower stations showed consistently higher maximum and minimum monthly averages during the months of June through September. The small difference between the monthly average maximum and minimum lake water temperatures at stations of different depths is interpreted as the result of frequent mixing of the waters in this portion of southeastern Lake Michigan. Considering the large range of natural lake water temperatures for both daily and monthly observations, the conclusion has been drawn that the impact of the natural lake water temperature fluctuations can

be related to the biota in this section of the lake and then use can be made of this base to interpret the influence of the man-made effluents and its resultant temperature changes on the aquatic community in southeastern Lake Michigan.

INTRODUCTION

With the advent of nuclear power plant construction, concern has been expressed as to what effect waste heat input from the generating stations will have on the lake as an aquatic environment. Temperature studies of the Lake Michigan drainage basin have been carried out by Church (1942, 1945), Ayers (1965), Noble (1967), Noble and Ewing (1967), Noble and Michaelis (1968), Mortimer (1971) and Hughes (1971a, 1971b). Dealing principally with the lake as a whole, these studies, all of which present both data and interpretations of their data, fail in the one aspect that we need detailed and extensive knowledge of what happens in the nearshore area. Beer (1971) deals with the nearshore area in the vicinity of Zion - Waukegan on southwestern Lake Michigan, with emphasis on mapping the thermal plume of the nuclear facility.

In determining the effect of a future heated effluent on a portion of the lake, it is meaningful to concentrate on the area where this effluent will exist and to understand the natural temperature variations that exist before the heated effluent is present.

With this in mind, a thermistor equipped submarine cable capable of recording lake water temperatures has been in use at the study location at the D. C. Cook Nuclear Plant on southeastern Lake Michigan south of Benton Harbor since May 1970 (Ayers et al. 1970). Local lake water temperatures are needed to determine if relationships can be found between the aquatic environment and

its natural temperature regime. According to the U. S. Fish and Wildlife Service (1970), "All available information indicates that each organism has specific thermal tolerances of limits that reflect the thermal requirements for each of the important functions in the individuals." If this is the case, it is important that we know the natural temperature fluctuations to which the organisms present in a particular area of the lake are normally subjected. This study investigated temperatures recorded at the Benton Harbor and St. Joseph water intakes in addition to the Cook Plant site with specifically that eventual goal in mind. Although it is difficult to establish and maintain a recording system from which the intensity of measurements is sufficient to make unequivocal statements about lake temperature, the knowledge of lake water temperatures over time will certainly contribute to more valid statements about natural relationships and later about the influence of the heated effluents of a generating facility on the lake biota.

DISCUSSION AND RESULTS

The lake water temperature recording system at the Cook Plant site has five thermistors attached. Two of the five thermistors are located 300 feet from shore in water depths of 2 and 4 feet; the remaining three thermistors are 2500 feet from shore in water depths of 2, 12, and 17 feet. The thermistors are held at their respective water depths by subsurface floats. Being located in the nearshore zone, these thermistors are subject to the forces that influence the nearshore zone, particularly wave and current action; this has resulted in periods when the system was not operational. To overcome this difficulty, for completeness, and for purposes of comparison, lake water temperatures

recorded at two nearby municipal water intakes have also been reported consistently (Ayers et al. 1970, 1972; Ayers and Seibel 1973). The water temperatures recorded at the Benton Harbor and St. Joseph water treatment plants are for raw water from intakes recorded 3375 feet from shore in 40 feet of depth and 1480 feet from shore in 19 feet of depth, respectively.

The daily minimum and maximum lake water temperatures recorded at the Cook Plant site and at the Benton Harbor and St. Joseph water plant intakes for the calendar year 1973, presented in Table 1, were examined to determine just how much natural lake water temperatures varied over time. The frequencies and magnitudes of the natural daily variations shown in Tables 2 and 3 for daily changes at the combined Benton Harbor-St. Joseph and the 2-foot and 12-foot thermistors at the 2500 feet from shore location off Cook Plant reveal substantial daily variations in the natural lake water temperatures. Using Tables 2 and 3, the percent of days that natural variations of 3°F or more occurred was calculated for the respective combined sites for the three 1.2-year periods of observations (Table 4).

The natural daily temperature fluctuations were divided into 3°F ranges, with the greatest range observed to date falling in the 27 to 29°F increment. Looking only at the percent of days that any month experienced a 3°F or more daily change (Table 4 and Fig. 1), we find that the two combined locations have similar patterns from month to month and that the daily fluctuations are most common in the months of May, June, July, August, and September, where the natural lake water temperature variation in excess of 3°F averages 20 percent of the days. During the months of June, July, August and September this natural variation occurs on an average of 50 percent of the days.

More meaningful than the total percent of days is the examination of the

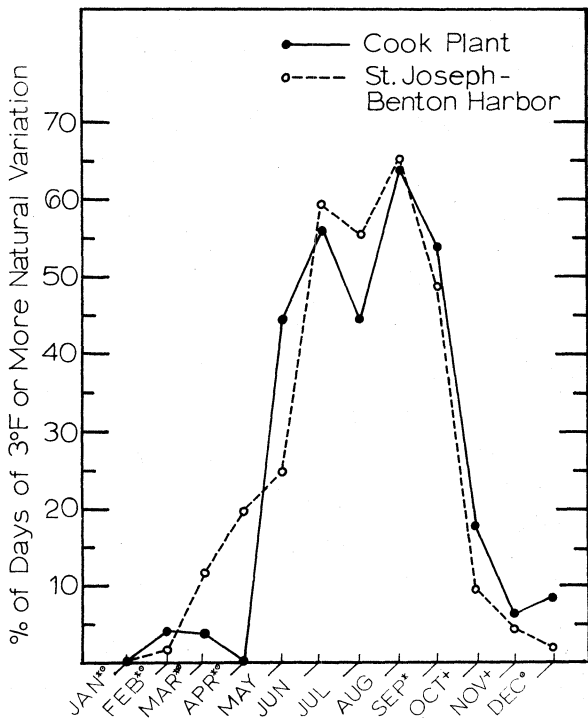


FIGURE 1. Percentage of days by month that the natural mean temperature range was 3°F or greater. Period of data 1970-1973. (*St. Joseph-Benton Harbor data for 1971-1973. ⁺Cook data for 1970, 1973. ^oCook data for 1971.)

TABLE 1. Daily minimum and maximum Lake Michigan water temperatures at the Cook Plant site and at the Benton Harbor (BH) and St. Joseph (SJ) water plant intakes in degrees Fahrenheit. Note: Blank spaces indicate that no data were obtained.

COOK PLANT						BH	SJ	
Offshore	300 Ft.		2500 Ft.			3375 Ft.	1490 Ft.	
Depth	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.	40 Ft.	19 Ft.	
JANUARY 1973								
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1						36 37	33	34.5
2						35 36	32.5	33.5
3						35 35	32.5	33
4						34 35	33	33.5
5						34 34	32	32.5
6						34 34	32	32.5
7						34 34	32	32.5
8						34 34	32	32.5
9						34 34	32	32.5
10						34 34	32	32
11						34 34	32	32.5
12						34 34	32	32.5
13						34 34	32	32.5
14						34 34	32	32.5
15						34 34	32	32.5
16						34 34	32	32
17			NOT IN OPERATION			34 34	32	32
18						34 35	32	33
19						35 36	32.5	33.5
20						35 35	32.5	34
21						35 35	33	35.5
22						35 35	33.5	34
23						35 36	33	34
24						35 36	33	33.5
25						36 36	33	33.5
26						36 36	33	34
27						36 37	33.5	34.5
28						36 37	33.5	35
29						35 36	32.5	33.5
30						35 36	32	32.5
31						35 35	32	34
MIN						34 34	32	32
MAX						36 37	33.5	35.5
AVE*						35 35	33	33

TABLE 1 continued.

Offshore	COOK PLANT					BH	SJ
	300 Ft.		2500 Ft.			3375 Ft.	1490 Ft.
Depth	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.	40 Ft.	19 Ft.

FEBRUARY 1973

<u>DATE</u>	<u>MIN</u>	<u>MAX</u>	<u>MIN</u>	<u>MAX</u>	<u>MIN</u>	<u>MAX</u>	<u>MIN</u>	<u>MAX</u>	<u>MIN</u>	<u>MAX</u>
1							35	36	33	34
2							36	37	34	34
3							36	36	34	34
4							36	37	34	34
5							36	37	34	36
6							36	37	35	36
7							36	37	34	36
8							35	37	33	36
9							35	36	33	33
10							35	35	33	33
11							35	35	33	34
12							35	35	33	33
13							35	35	33	33
14							34	35	33	33
15							34	35	32	34
16							34	34	32	32
17			NOT IN OPERATION				34	34	32	32
18							34	34	32	32
19							34	34	32	32
20							34	34	32	32
21							34	34	32	32
22							34	34	32	32
23							34	34	32	33
24							34	34	32	33
25							34	34	32	33
26							34	34	32	33
27							34	34	33	33
28							34	34	33	33
29										
30										
31										
MIN							34	34	32	32
MAX							36	37	35	36
AVE*							35	35	33	33

TABLE 1 continued.

	COOK PLANT						BH		SJ	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
Depth	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
MARCH 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1							34	36	33	34
2							35	36	34	34.5
3							36	36	34.5	35
4							35	36	34.5	35
5							36	36	36.5	38
6							36	37	36	38
7							37	42	36	38
8							41	44	37.5	39
9							40	42	36	41
10							38	39	40.5	41.5
11							39	44	40	41
12							41	44	38.5	40
13							42	43	40	41
14							42	44	40.5	42
15							43	46	41.5	43
16			NOT IN OPERATION				41	44	41	46
17							41	42	41	45
18							40	40	38	39.5
19							39	40	38.5	40.5
20							39	40	39	40.5
21							39	40	38.5	41.5
22							39	40	38	40.5
23							40	43	39	39.5
24							41	42	39	41
25							40	41	40.5	41
26							40	41	40.5	44.5
27							40	42	41	43.5
28							42	45	40.5	41.5
29							43	45	39.5	43
30							42	43	42.5	44
31							42	44	41	43
MIN							34	36	33	34
MAX							44	45	42.5	46
AVE*							39	41	39	41

TABLE 1 continued.

	COOK PLANT					BH	SJ		
Offshore	300 Ft.		2500 Ft.			3375 Ft.	1490 Ft.		
Depth	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.	40 Ft.	19 Ft.		
APRIL 1973									
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	
1						42	43	40.5	42.5
2						42	46	42	42.5
3						44	45	42	44
4						43	44	42	44
5						42	46	41	44
6						45	46	42	44
7						44	45	43.5	44
8						44	45	43	45
9						44	45	42	43.5
10						45	46	42	43
11						43	45	41.5	42
12						45	45	42	46
13						44	45	42	44.5
14						44	46	42	43.5
15						46	49	43	44
16						48	49	44	45
17			NOT IN OPERATION			48	49	45	45.5
18						48	50	45	45.5
19						48	48	45	45.5
20						49	50	46	48
21						50	50	48	48.5
22						50	51	48.5	49
23						49	51	46	49
24						48	49	45	47.5
25						48	48	47	49
26						48	48	45	49
27						48	48	46	51
28						48	48	45	50
29						48	49	45	46
30						48	48	46	46
31									
MIN						42	43	40.5	42.5
MAX						50	51	48.5	51
AVE*						46	47	44	46

TABLE 1 continued.

Offshore	COOK PLANT						BH		S.J	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
MAY 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1							48	50	45	48
2							50	51	48	50
3							50	52	47	50
4							50	51	47	48
5							50	50	47	48
6							50	50	48	49
7							51	51	48	50
8							51	53	50	51
9							52	52	50	51
10							53	53	51	52
11							54	55	52	53
12							54	55	52	54
13							53	54	52	53
14							53	53	51	53
15							52	53	52	53
16							53	54	52	53
17			NOT IN OPERATION				53	54	53	54
18							53	54	52	53
19							53	54	52	53
20							52	53	51	53
21							52	52	51	55
22							52	54	52	53
23							52	53	51	53
24							51	52	50	53
25							52	55	52	54
26							55	56	54	55
27							52	55	51	54
28							51	52	50	52
29							49	50	50	51
30							49	50	49	51
31							50	53	49	53
MIN							48	50	45	48
MAX							55	56	54	55
AVE*							52	53	50	52

TABLE 1 continued.

Offshore	COOK PLANT						BH		SJ	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
JUNE 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1							53	54	52	55
2							54	56	54	57
3							55	57	57	58
4							57	58	58	59
5							58	59	59	61
6							58	59	60	62
7							58	61	62	63
8							61	62	62	64
9							62	62	63	64
10							62	63	62	64
11							62	64	64	66
12							63	65	64	67
13							55	64	56	66
14							52	56	52	60
15							51	55	52	62
16			NOT IN OPERATION				54	66	62	66
17							57	66	65	66
18							56	64	66	67
19							62	68	66	69
20							59	69	68	71
21							68	70	70	72
22							68	70	70	71
23							68	70	69	70
24							67	69	66	69
25							54	68	60	68
26							54	69	66	70
27							69	70	70	70
28							69	71	70	71
29							69	70	70	71
30							69	70	70	71
31										
MIN							51	54	52	55
MAX							69	71	70	72
AVE*							60	64	63	66

TABLE 1 continued.

COOK PLANT						BH		SJ		
Offshore	300 Ft.		2500 Ft.			3375 Ft.		1490 Ft.		
Depth	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.	40 Ft.		19 Ft.		
JULY 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1						69	70	69.5	71	
2						65	61	69.5	71	
3						65	71	71	71.5	
4						62	72	71	72	
5						67	70	71	72	
6						58	70	70	71.5	
7						56	74	71.5	74.5	
8						57	75	74.5	76	
9						70	75	76	77	
10						57	73	50	76	
11						62	71	47.5	52	
12						49	56	47.5	54	
13						57	66	54	68	
14						64	69	67	68	
15						65	69	68	70	
16						64	67	67	68	
17			NOT IN OPERATION			62	66	66	67	
18						58	68	63	66.5	
19						56	69	54.5	68.5	
20						55	68	64	73	
21						52	56	57	68.5	
22						51	52	49	59	
23						50	53	49	52	
24						51	57	49.5	56	
25						51	59	51	60	
26						51	62	53	70	
27						60	74	70	72	
28						73	73	72	72.5	
29						72	73	72	74	
30						73	74	73.5	74.5	
31						74	75	74	75	
MIN						49	52	47.5	52	
MAX						74	75	76	77	
AVE*						61	68	63	68	

TABLE 1 continued.

Offshore Depth	COOK PLANT						BH		SJ	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
AUGUST 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1	65	66	65	67	62	66	64	66	74	74
2	63	65	64	66	62	65	64	66	73	59
3	63	66	64	68	62	64	63	66	55	69
4	62	66	64	68	63	64	64	66	68	70
5	64	67	65	69	63	66	65	67	70	73
6	66	68	67	69	65	67	66	67	72	75
7	65	68	67	69	66	67	66	67	75	76
8	66	69	68	70	66	67	66	68	76	77
9	67	69	69	71	67	67	67	68	76	77
10	68	72	69	72	66	67	68	69	76	77
11	68	70	69	71	67	68	68	69	76	77
12	68	70	68	71	64	67	68	69	75	77
13	66	70	67	71	55	66	68	69	64	72
14	64	68	66	69	44	58	56	69	55	68
15	45	65	46	66	43	51	44	62	51	54
16	51	63	58	65	51	61	55	63	51	62
17	61	66	63	68	60	63	62	66	59	68
18	63	68	64	69	61	65	63	67	61	70
19	64	66	65	67	63	66	65	66	66	70
20	64	66	65	66	59	67	65	66	70	74
21	47	64	47	66	44	59	44	65	52	70
22	45	50	46	53	44	49	45	52	51	53
23	47	54	50	56	49	55	50	57	51	53
24	49	54	51	56	46	52	51	55	51	53
25	45	50	47	52	45	48	47	54	50	52
26	47	49	50	53	45	49	48	53	49	50
27	49	57	52	60	44	56	49	61	50	56
28	54	60	56	63	52	59	55	60	58	65
29	60	62	63	65	50	60	59	64	57	69
30	63	66	65	70	53	62	62	66	55	71
31	64	66	66	69	50	65	65	66	62	73
MIN	45	50	56	52	43	48	44	52	49	50
MAX	68	72	69	72	67	68	68	69	76	77
AVE*	59	64	61	65	56	61	59	64	62	68

TABLE 1 continued.

Offshore	COOK PLANT						BH		SJ	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
SEPTEMBER 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1	66	68	66	69	65	67	65	67	74	76
2	66	68	67	70	66	67	67	67	76	77
3	68	70	69	71	66	68	67	69	75	78
4	68	70	69	70	68	69	68	69	77	77.5
5	68	71	68	71	68	69	68	69	77	77.5
6	67	70	67	70	68	69	67	69	75.5	78
7	66	68	66	68	67	68	67	68	75	76
8	65	68	65	68	44	68	66	68	53	75
9	47	66	48	66	43	45	46	66	51	64
10	46	63	46	64	43	45	45	65	50	69.5
11	51	63	51	64	43	63	47	64	51	69
12	46	62	46	62	43	52	45	61	49	51
13	45	60	46	60	44	51	45	59	49	52
14	45	48	46	50	42	45	43	55	48	49
15	44	49	45	50	43	44	44	48	48	49
16	47	50	48	51	44	51	45	52	48	50
17	47	50	49	51	46	51	49	53	50	51
18	46	51	47	52	44	54	45	55	48	54
19	50	54	50	55	54	55	55	56	54	58
20	53	55	53	55	54	55	54	55	58	60
21	52	54	52	54	51	54	52	54	54	59
22			53	56	52	54	53	55	55	59
23			55	56	53	55	54	55	54	55
24			54	55	53	54	54	55	54	55
25			55	56	53	54	54	55	53	55
26			55	58	54	56	55	57	55	56
27			56	59	55	57	56	57	55	57
28			57	58	55	56	56	58	56	57
29			57	58	53	57	54	58	55	58
30			54	57	50	53	52	55	52	55
31									57	60
MIN	44	49	45	50	42	44	43	48	48	49
MAX	68	71	69	71	68	69	56	58	68	69
AVE*	55	61	55	60	53	57	51	54	54	59

		COOK PLANT					BH		SJ	
Offshore	300 Ft.		2500 Ft.			3375 Ft.		1490 Ft.		
Depth	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.	40 Ft.		19 Ft.		
OCTOBER 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1		51 54	48 52	48 54	49 55	53 59	54 59			
2		52 56	48 54	53 56	53 55	52 56	55 59			
3		55 57	53 55	54 56	54 55	60 62	58 61			
4		55 56	54 56	55 56	55 55	60 62	61 63			
5			56 60	56 61	55 61	59 62	61 62			
6			59 61	60 62	60 63	60 62	61 61			
7			60 61	60 62	60 62	61 62	61 61			
8			59 61	61 63	60 62	60 62	61 62			
9			60 63	62 64	61 63	61 63	61 63			
10			62 63	63 64	62 64	63 64	63 64			
11			62 63	63 64	63 64	63 64	64 64			
12			62 63	63 64	63 64	64 64	64 65			
13			62 63	63 64	62 63	64 64	64 65			
14			62 63	62 63	62 63	64 65	63 64			
15			61 62	62 63	61 62	64 65	63 64			
16			59 61	60 62	59 61	63 64	61 63			
17			57 59	58 60	58 59	60 61	59 61			
18			56 58	57 60	57 59	61 59	60 61			
19			55 57	57 58	55 58	60 59	60 61			
20			56 58	57 59	56 59	60 61	59 60			
21			56 57	58 59	57 59	60 60	59 60			
22			56 57	57 59	57 58	60 59	59 59			
23			56 58	57 59	57 58	60 59	58 59			
24			57 58	58 59	57 58	60 59	59 59			
25			57 58	58 59	57 58	60 59	59 59			
26			57 58	58 59	57 58	60 59	58 59			
27			56 58	57 59	57 58	60 58	58 58			
28			55 57	56 58	56 57	59 60	57 58			
29			54 56	55 57	54 56	59 59	56 58			
30			54 55	55 56	54 55	58 59	56 57			
31			54 55	55 56	54 55	57 58	55 57			
MIN		51 54	48 52	48 54	49 55	52 56	54 57			
MAX		55 57	62 63	63 64	63 64	64 65	64 65			
AVE*		53 55	57 59	58 60	58 59	60 61	60 61			

TABLE 1 continued.

Offshore	COOK PLANT						BH		S.J	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
Depth										
NOVEMBER 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1			52	54	53	55	52	54	57	57
2			51	52	53	53	52	53	56	56
3			51	52	52	53	51	52	56	56
4			50	52	52	53	51	52	55	56
5			49	51	50	52	49	51	55	55
6			48	49	49	51	48	50	53	55
7			47	48	48	50	47	49	52	53
8			47	49	48	50	47	49	52	52
9			45	47	46	48	45	48	51	51
10			45	46	46	47		48	49	51
11			44	46	46	48		48	50	50
12			45	47	46	48		46	49	50
13			46	47	47	48	46	47	49	49
14			46	49	47	50	47	50	49	50
15			47	49	49	50	46	51	50	51
16			45	47	47	49	46	49	50	51
17			44	46	46	48		47	49	50
18			45	46	47	48	45	48	49	50
19			45	46	47	48	46	47	50	50
20			45	46	47	48	46	48	50	50
21			45	47	47	49	46	49	50	50
22			45	46	47	48	46	48	50	50
23			45	46	48	48	47	48	50	50
24			45	47	47	48	46	49	50	50
25			45	47	45	48	45	48	50	50
26			45	47			45	48	50	50
27			46	47			46	50	50	50
28			45	46			46	48	49	50
29									48	49
30									48	49
31										
MIN			44	46	45	47	45	46	48	49
MAX			52	54	53	55	52	54	57	57
AVE*			46	48	48	50	47	49	51	51

TABLE 1 continued.

Offshore	COOK PLANT						BH		SJ	
	300 Ft.		2500 Ft.				3375 Ft.		1490 Ft.	
	2 Ft.	4 Ft.	2 Ft.	12 Ft.	17 Ft.		40 Ft.		19 Ft.	
DECEMBER 1973										
DATE	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX
1							48	48	46	46
2							47	48	46	46
3							48	48	45	46
4							47	48	46	47
5							48	48	45	46
6							46	48	44	46
7							46	47	44	45
8							46	47	43	45
9							46	47	43	44
10							46	46	40	43
11							41	46	40	42
12							41	42	39	41
13							41	42	38	40
14							40	42	40	41
15							39	40	38	40
16							40	41	40	41
17			NOT IN OPERATION				40	40	35	36
18							37	39	37	38
19							37	39	35	38
20							38	38	35	36
21							37	38	35	36
22							35	36	34	35
23							36	37	34	36
24							37	37	35	35
25							37	37	35	36
26							37	37	36	36
27							37	37	36	37
28							37	37	36	36
29							37	38	35	36
30							35	38	34	35
31							35	35	35	35
MIN							35	35	34	35
MAX							48	48	46	47
AVE*							41	42	39	40

* Average temperatures rounded to the nearest whole degree Fahrenheit.

TABLE 2. Frequences and magnitudes of natural daily temperature changes at Benton Harbor and St. Joseph water filtration plants in 1970 through 1973.

Daily change °F	January				February				March				April				May				June			
	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73
3 - 5	ND	-	-	-	ND	1	-	-	ND	2	5	14	ND	11	15	8	13	10	16	8	19	26	30	11
6 - 8	ND	-	-	-	ND	1	-	-	ND	-	-	-	ND	-	-	-	1	2	2	-	6	9	5	4
9 - 11	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	6	2	4	5
12 - 14	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	3	1	2	2
15 - 17	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	2	-	-	1
18 - 20	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	2	1	-	-
21 - 23	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-
24 - 26	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-
27 - 29	ND	-	-	-	ND	-	-	-	ND	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-
2-Plant monthly Fraction	ND	0	0	0	ND	2	0	0	ND	2	5	14	ND	11	15	8	14	12	18	8	38	39	41	23
	62	62	62	62	56	58	56	56	62	62	62	62	60	60	60	60	42	58	62	62	60	60	59	60

Daily change °F	July				August				September				October				November				December			
	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73
3 - 5	17	17	26	12	16	17	21	16	ND	5	17	11	3	5	-	4	2	2	1	5	-	-	2	3
6 - 8	2	11	2	8	16	7	2	7	ND	7	10	2	1	2	-	2	-	-	-	-	-	-	-	-
9 - 11	1	6	-	7	11	9	3	6	ND	4	10	1	-	-	-	-	-	-	-	-	-	-	-	-
12 - 14	-	1	3	7	1	4	1	4	ND	4	1	6	-	-	-	-	-	-	-	-	-	-	-	-
15 - 17	1	5	1	2	2	1	1	5	ND	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-
18 - 20	2	1	-	2	2	2	-	1	ND	-	1	4	-	-	-	-	-	-	-	-	-	-	-	-
21 - 23	-	-	-	-	-	1	-	-	ND	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-
24 - 26	1	-	-	1	-	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
27 - 29	-	-	-	-	-	-	-	-	ND	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2-Plant monthly Fraction	24	41	32	39	48	41	27	39	ND	20	40	27	4	7	0	6	2	2	1	5	0	0	2	3
	62	61	62	62	62	62	62	62	62	60	60	60	62	62	62	62	60	60	60	60	62	62	62	62

ND = No data.

- = This magnitude of temperature variation was not reached.

TABLE 3. Frequencies and magnitudes of natural daily temperature changes at the 2 foot and 12 foot thermistors at the 2,500 foot position off the Cook Plant in 1970 through 1973.

Daily change °F	January				February				March				April				May				June			
	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73
3 - 5	ND	-	ND	ND	ND	2	ND	ND	ND	2	ND	ND	ND	-	ND	ND	16	4	20	ND	18	9	19	ND
6 - 8	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	2	3	2	ND	10	-	16	ND
9 - 11	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	-	ND	4	1	8	ND
12 - 14	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	1	ND	3	2	7	ND
15 - 17	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	1	ND	1	-	-	ND
18 - 20	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	-	ND	2	-	-	ND
21 - 23	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	-	ND	-	-	-	ND
24 - 26	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	-	ND	-	-	-	ND
27 - 29	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	ND	-	ND	ND	-	-	-	ND	-	-	-	ND
2-Depth monthly Fraction	0				2				2				0				18 7 24				38 12 50			
	ND	62	ND	ND	ND	56	ND	ND	ND	62	ND	ND	ND	62	ND	ND	42	58	32	ND	60	60	59	ND

Daily change °F	July				August				September				October				November				December			
	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73	70	71	72	73
3 - 5	17	4	25	ND	11	ND	18	8	9	ND	32	8	14	ND	ND	6	3	ND	ND	3	3	ND	ND	ND
6 - 8	2	6	8	ND	8	ND	8	4	5	ND	5	4	1	ND	ND	2	-	ND	ND	-	-	ND	ND	ND
9 - 11	-	3	2	ND	8	ND	3	4	-	ND	4	4	2	ND	ND	-	-	ND	ND	-	-	ND	ND	ND
12 - 14	-	1	1	ND	4	ND	-	3	1	ND	2	-	-	ND	ND	-	-	ND	ND	-	-	ND	ND	ND
15 - 17	-	1	-	ND	-	ND	2	2	7	ND	-	-	-	ND	ND	-	-	ND	ND	-	1	ND	ND	ND
18 - 20	1	-	-	ND	-	ND	-	-	2	ND	-	1	-	ND	ND	-	-	ND	ND	-	-	ND	ND	ND
21 - 23	-	-	-	ND	-	ND	-	-	-	ND	-	-	-	ND	ND	-	-	ND	ND	-	-	ND	ND	ND
24 - 26	2	-	-	ND	-	ND	-	-	-	ND	-	1	-	ND	ND	-	-	ND	ND	-	-	ND	ND	ND
27 - 29	1	-	-	ND	-	ND	-	-	-	ND	-	-	-	ND	ND	-	-	ND	ND	-	-	ND	ND	ND
2-Depth monthly Fraction	23 15 36				31				31 21 24				43 18 17				8 3				3 4			
	62	54	54	ND	46	ND	62	31	50	ND	58	48	64*	ND	ND	62	50	ND	ND	53	52	ND	ND	ND

ND = No data.

- = This magnitude of temperature variation was not reached.

* = 2 sets of data on one day.

TABLE 4. Percent of days that natural variations of 3°F or more occurred.
(From the monthly fractions of Tables 2 and 3.)

Month & Year		BH - SJ	4-year average %	Cook Plant	4-year average %
January	1970	no data		no data	
	1971	0.0		0.0	
	1972	0.0		no data	
	1973	0.0	0.0	no data	0.0
February	1970	no data		no data	
	1971	3.6		3.6	
	1972	0.0		no data	
	1973	0.0	1.2	no data	3.6
March	1970	no data		no data	
	1971	3.2		3.2	
	1972	8.1		no data	
	1973	22.6	11.3	no data	3.2
April	1970	no data		no data	
	1971	18.3		0.0	
	1972	25.0		no data	
	1973	13.3	18.9	no data	0.0
May	1970	33.3		42.8	
	1971	20.7		12.1	
	1972	29.0		75.0	
	1973	12.9	24.0	no data	43.3
June	1970	63.3		63.3	
	1971	65.0		20.0	
	1972	69.5		84.7	
	1973	38.3	59.0	no data	56.0
July	1970	38.7		37.1	
	1971	67.2		27.8	
	1972	51.6		66.7	
	1973	62.9	55.1	no data	43.9
August	1970	77.4		67.4	
	1971	66.1		no data	
	1972	43.5		50.0	
	1973	62.9	62.5	67.7	61.7
September	1970	no data		48.0	
	1971	33.3		no data	
	1972	66.6		74.1	
	1973	45.0	48.3	37.5	53.2
October	1970	6.4		26.6	
	1971	11.3		no data	
	1972	0.0		no data	
	1973	9.7	9.1	12.9	19.8

TABLE 4 continued.

Month & Year		BH - SJ	4-year average %	Cook Plant	4-year average %
November	1970	3.3		6.0	
	1971	3.3		no data	
	1972	1.7		no data	
	1973	8.3	4.2	5.7	5.9
December	1970	0.0		7.7	
	1971	0.0		no data	
	1972	3.2		no data	
	1973	4.8	2.0	no data	7.7

breakdown of the natural lake water temperature variation into its respective 3°F increments for the period May 1970 through December 1973. This breakdown for the combined Benton Harbor-St. Joseph and for the 2-foot and 12-foot thermistors of the 2500 feet from shore location at Cook tabulated in Tables 5 and 6 and shown graphically in Figure 2 reveals that of the total 2866 sampling days for Benton Harbor-St. Joseph a natural lake water temperature variation of 3°F or more occurred 660 days or 25.6 percent of the sample. Of the Cook site's total 1299 sampling days the variation of 3°F or more occurred on 430 days or 33.1 percent of the sample. These data further reveal that a daily variation in the natural lake water temperatures of up to 11°F was recorded for 380 of 1299 days or 29 percent at Cook and for 575 of 2586 days or 22 percent at the Benton Harbor-St. Joseph locations respectively.

The triaxial distribution of the natural lake water temperatures (Fig. 3) indicates that natural variations for the period of record are most frequent in the 3-5°F range. As the range increases, the months in which the

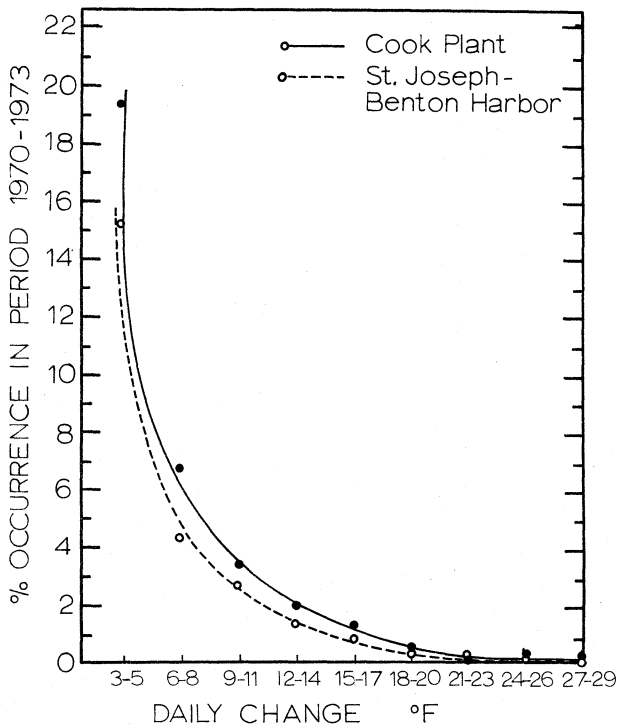


FIGURE 2. Natural Lake Michigan temperature variations in 3°F increments for the period 1970-1973 at the combined 2-ft and 12-ft thermistors of the 2500 ft from shore location at Cook and the combined St. Joseph-Benton Harbor data.

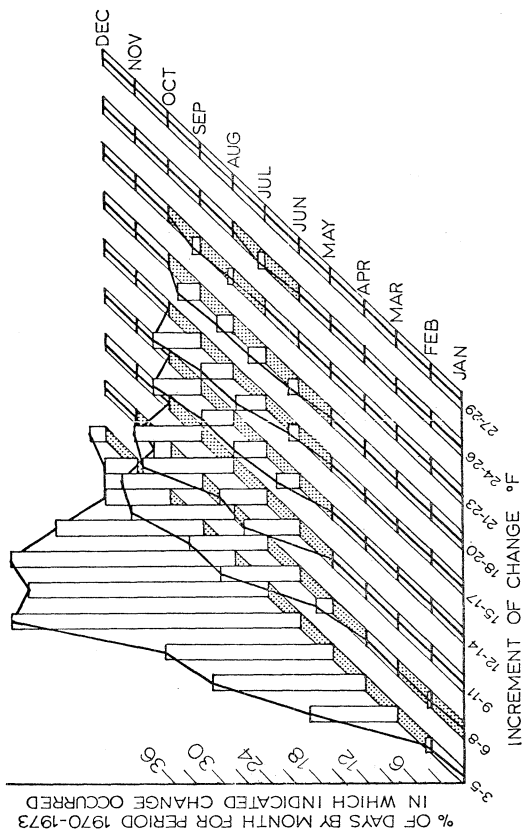


FIGURE 3. Triaxial representation of the natural lake water temperature variation in percent by month and in 3°F increment for the St. Joseph-Benton Harbor location.

TABLE 5. Total number of days per month for the period 1970 through 1973 in which daily change of indicated °F occurred at the Benton Harbor and St. Joseph water filtration plants.

Daily change °F	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	%
3 - 5	0	1	21	34	47	86	72	70	33	12	10	5	391	15.1
6 - 8	0	1	0	0	5	24	23	32	19	5	0	0	109	4.2
9 - 11	0	0	0	0	0	17	14	29	15	0	0	0	75	2.9
12 - 14	0	0	0	0	0	7	11	10	11	0	0	0	39	1.5
15 - 17	0	0	0	0	0	3	9	9	2	0	0	0	23	0.9
18 - 20	0	0	0	0	0	3	5	5	5	0	0	0	18	0.7
21 - 23	0	0	0	0	0	0	0	1	2	0	0	0	3	0.12
24 - 26	0	0	0	0	0	0	2	0	0	0	0	0	2	0.08
27 - 29	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
TOTAL	186	170	186	180	224	239	237	248	180	248	240	248	660 2586	25.5

variations occur narrow so that when one finds variations of as much as 20°F they are concentrated in the months of June, July, August and September. The maximum daily variation recorded in this period was 27°F and occurred at the 2-foot depth of the 2500 feet from shore location at the Cook Plant site on 20 July 1970. On that day the daily change at the 12-foot depth was 24°F and at the 17-foot depth at Cook it was also 27°F. At the Benton Harbor intake at the depth of 40 feet the change was 18°F, and at the St. Joseph intake at a depth of 19 feet the lake water temperature change was 24°F. The Benton Harbor intake, at twice the depth

TABLE 6. Total number of days per month for the period 1970 through 1973 in which daily change of indicated °F occurred at the Cook Plant 2 ft and 12 ft thermistors of the 2500 ft from shore position.

Daily change °F	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	%
3 - 5	0	2	2	0	40	46	46	37	49	20	6	3	251	19.3
6 - 8	0	0	0	0	7	26	16	20	14	3	0	0	86	6.6
9 - 11	0	0	0	0	0	13	5	15	8	2	0	0	43	3.3
12 - 14	0	0	0	0	1	12	2	7	3	0	0	0	25	1.9
15 - 17	0	0	0	0	1	1	1	4	7	0	0	1	15	1.2
18 - 20	0	0	0	0	0	2	1	0	3	0	0	0	6	0.5
21 - 23	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
24 - 26	0	0	0	0	0	0	2	0	1	0	0	0	3	0.2
27 - 29	0	0	0	0	0	0	1	0	0	0	0	0	1	0.1
TOTAL	62	56	62	62	132	179	170	139	156	126	103	52	430 1299	33.1

of any of the other stations, showed on that day a natural temperature change of 18°F.

This type of extreme daily temperature fluctuation is best explained by upwelling of cooler deeper water into the nearshore zone. When this occurs, the surface waters of the near shore are moved offshore by surface winds and replaced by the cooler deeper lake waters. Direct wind-induced upwelling is thought to account for the temperature variations in excess of 12°F. This magnitude of change is most frequent during the months of June, July, August, and September for both locations and occurred about 3.5 to 4 percent of the total sample days of record, but accounts

for between 8 and 9 percent of sample days during the months of June through September. Although the present study has made no comparisons of temperature variations on the western shore of Lake Michigan, Mortimer (1971) indicated that the temperature "rise and fall are highest on the eastern shore, where the highest maximum temperatures are attained (and maintained for longer periods)." In part, all the fluctuations in the natural lake water temperatures are thought to be produced by some form of upwelling, with the most extreme variations being primarily wind induced while the less extreme changes are produced by combinations of wind and internal wave phenomena. The frequency of the natural temperature fluctuations reported is such that if one can assume that the variation is at least partially produced by upwelling, then it is plausible to state that upwelling in this portion of Lake Michigan is a common event and not the exception.

Until now the concentration has been on examining what type of fluctuations occur on the daily basis, but equally important in terms of the effect of temperature fluctuation on the lake environment are the long-term changes that occur within the month of the year. Looking at the natural temperature variations over the months at the two water intake locations at Benton Harbor and St. Joseph stations, one observes some remarkable similarities. The most important single result is that the monthly temperature fluctuations at the two stations are similar in both their minimum and their maximum temperature ranges. Similar to the daily fluctuations, the greatest fluctuations of the minimum and maximum monthly temperatures occur in the months of June through September where the monthly fluctuations are near 20°F. For the months of April through May the fluctuations are near 10°F, as they are for October and November, with a variable fluctuation in December depending on the year, and

the greatest fluctuation having occurred in December 1973. The months of January and February show the least of the maximum and minimum temperatures. A summary of this data is given in Tables 7 and 8 and shown graphically in Figures 4 and 5. Figure 4 indicates that the deeper water station at Benton Harbor has higher lake water temperature averages in the months of January, February and March for both the average maximum and minimum temperatures. While the deep-water station at Benton Harbor (depth 40 ft) shows a consistently lower lake water temperature during July, August and September for all three years, the close fit of the two curves in Figure 4 illustrates that the average minimum and average maximum monthly temperatures for the two stations differ little. The difference between the average maximum and average minimum for each station differs only slightly from year to year. These two factors indicate that the average monthly conditions for the two stations are similar and indicate a greater amount of mixing in the nearshore waters of this southeastern portion of Lake Michigan than has been known before. The fact that this mixing of nearshore waters is indicated leads to interpolation that higher temperature waters than the receiving waters would be incorporated within the local waters quickly and hence reduce the impact of high temperature waters introduced into the nearshore system on the nearshore lake environment.

The data presented in Ayers et al. (1970, 1972) and Ayers and Seibel (1973) and that given in Table 1 here was examined to determine if the natural lake water temperatures at these recording stations fall within the guidelines that the "Great Lakes and connecting waterways shall not receive a heat load which would warm the receiving waters at the edge of the mixing zone to temperatures in degrees Fahrenheit higher than the following monthly temperatures: Jan. 45, Feb. 45, March 45, April 55, May 60, June 70, July 80, August 80,

TABLE 7. Summary of the minimum and maximum monthly water temperatures including averages and temperature ranges in degrees Fahrenheit at the St. Joseph water intake for the period 1971-1973.

Month	1971			1972			1973			Δ min - Δ max		ΔT
	Min T range	Ave min	Max T range max	Min T range min	Ave min	Max T range max	Min T range min	Ave min	Max T range max	Δ min	Δ max	
Jan	32/ 33	32	32/ 33	32/ 36	33	32/ 36	32/ 34 ⁺	33	32/ 36 ⁺	33	1 4 2 ⁺	1 4 4 ⁺ 0 0 0
Feb	32/ 33	32	32/ 33	32/ 32	32	32/ 32	32/ 35	33	32/ 36	33	1 0 3	1 0 4 0 0 0
Mar	32/ 35	32	32/ 37	30/ 34	33	31/ 37	33/ 43 ⁺	39	34/ 46	41	3 4 10 ⁺	7 6 12 1 1 2
Apr	36/ 46	41	38/ 50	34/ 45	40	36/ 48	41 ⁺ / 49 ⁺	44	43 ⁺ / 51	46	10 11 8	12 12 9 ⁺ 3 2 2
May	45/ 55	49	47/ 57	43/ 54	46	44/ 57	45/ 54	50	48/ 55	52	10 11 11	10 13 7 3 2 2
Jun	51/ 64	56	52/ 72	45/ 61	52	48/ 64	52/ 70	63	55/ 72	66	13 16 18	20 16 17 4 5 3
Jul	48/ 72	62	52/ 74	43/ 76	60	46/ 78	48/ 76	63	52/ 77	68	24 33 26	22 32 25 5 2 5
Aug	49/ 69	60	53/ 73	45/ 72	62	49/ 72	49/ 77	65	50/ 78	70	20 27 26	20 23 28 6 3 5
Sep	54/ 72	64	60/ 73	50/ 69	57	52/ 72	47/ 77	59	49/ 78	64	18 19 30	13 20 29 3 5 5
Oct	51/ 65	58	54/ 66	50/ 58	54	50/ 58	54/ 64	60	57/ 65	61	14 8 10	12 8 8 1 0 1
Nov	40/ 56	48	42/ 58	38/ 50	45	39/ 51	46/ 54	49	47/ 57	50	16 12 8	16 12 10 1 1 1
Dec	36/ 40	38	37/ 41	32/ 39	34	32/ 39	34/ 46	39	35/ 47	40	4 7 12	4 7 12 1 1 1

⁺ Rounded to the nearest whole degree Fahrenheit.
 *All Average temperatures rounded to the nearest whole degree Fahrenheit.
 ΔT = Average maximum - average minimum.

TABLE 8. Summary of the minimum and maximum monthly water temperatures including averages and temperature ranges in degrees Fahrenheit at the Benton Harbor water intake for the period 1971-1973.

Month	1971			1972			1973			Δ min		Δ max		ΔT		
	Min T range	Ave min	Max T range max	Min T range	Ave min	Max T range max	Min T range	Ave min	Max T range max	71	72	73	71		72	73
Jan	32/ 38	35	32/ 39	32/ 35	34	33/ 36	34/ 36	35	34/ 37	35	6	3	2	7	3	3
Feb	33/ 37	35	34/ 39	33/ 34	34	33/ 34	34/ 36	35	34/ 37	35	4	1	2	5	1	3
Mar	35/ 39	37	36/ 41	33/ 36	34	35/ 38	34/ 44	36	36/ 45	41	4	3	10	5	3	9
Apr	37/ 49	44	40/ 50	36/ 46	41	37/ 47	42/ 50	42	43/ 51	47	12	10	8	10	10	8
May	49/ 59	53	50/ 59	43/ 53	47	44/ 56	48/ 55	48	50/ 56	53	10	10	7	9	12	7
Jun	51/ 73	56	51/ 74	47/ 61	53	49/ 63	51/ 69	56	54/ 71	64	22	14	18	23	14	17
Jul	48/ 72	58	51/ 73	45/ 70	57	45/ 74	49/ 74	61	52/ 75	68	24	25	25	22	29	23
Aug	48/ 68	57	50/ 70	47/ 71	61	49/ 73	49/ 76	65	50/ 77	68	20	24	27	20	24	27
Sep	53/ 69	61	56/ 70	50/ 69	57	52/ 72	48/ 77	62	49/ 78	62	16	19	29	14	20	29
Oct	51/ 64	58	53/ 64	52/ 58	55	52/ 60	52/ 64	56	56/ 65	61	13	6	12	11	8	9
Nov	41/ 57	47	42/ 57	40/ 52	47	41/ 52	48/ 57	48	49/ 57	51	16	12	9	15	11	8
Dec	35/ 40	37	35/ 41	34/ 40	36	34/ 41	35/ 48	37	35/ 48	42	5	6	13	6	7	13

*All Average temperatures rounded to the nearest whole degree Fahrenheit.

ΔT = Average maximum - average minimum.

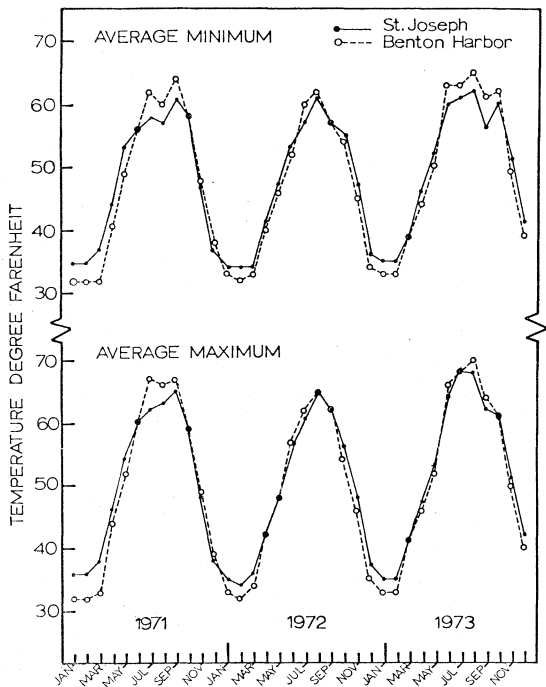


FIGURE 4. A comparison of the average minimum and average maximum lake temperatures at the St. Joseph and Benton Harbor water intakes. The Benton Harbor intake is at a depth of 40 ft and the St. Joseph intake at a depth of 19 ft.

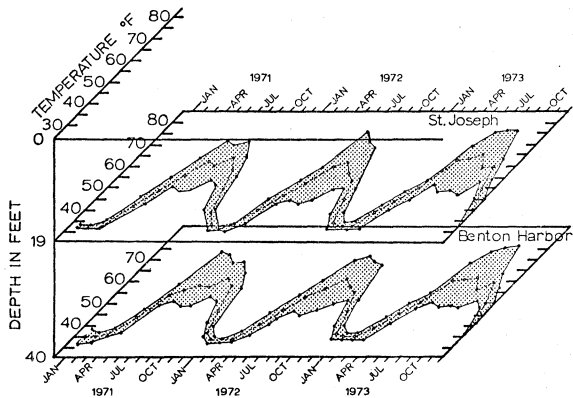


FIGURE 5. Range in temperature by month for the period 1971-1973 at the St. Joseph and Benton Harbor water intakes.

September 80, October 65, November 60, and December 50 for Lake Michigan south of a line due west from the city of Pentwater." (Michigan Water Resources Commission 1973). The data reveal that these maximum temperatures were exceeded (Table 9) at the Benton Harbor-St. Joseph water intakes by 10% in June 1971, 26.7% in June 1973, 9.7% in October 1971, 8.1% in March 1973 and 6.5% of the days in October 1973. At the Cook site the maximum recommended temperature was exceeded by 6.7% and 30% of the days in June 1970 and 1971 respectively. It is valid to point out that even carefully selected maximum lake water temperature standards can be exceeded naturally, and in fact are exceeded naturally.

CONCLUSIONS

This study points out pertinent facts in regard to the natural temperature fluctuations that occur in the nearshore water of southeastern Lake Michigan:

- 1) Natural lake water fluctuations in excess of 3°F are a common occurrence in most months with the singular exception of January.
- 2) The greatest temperature fluctuations occur during the summer months of June, July, August and September where natural variations of up to 27°F were recorded during the three 1.2 years of the study.
- 3) Varying amounts of upwelling of colder deeper offshore waters can best explain the natural temperature variations that occur on a daily basis. Wind induced upwelling is thought responsible for the natural daily fluctuations in excess of 12°F, while a combination of wind and internal wave movement seems a plausible explanation for the smaller variations.
- 4) In the same region on the same side of the lake, water temperatures from different depth show the percent of occurrence of the natural lake water

TABLE 9. Numbers of days the natural lake temperature exceeded the recommended monthly maximum temperatures* of Lake Michigan south of a line due west from the city of Pentwater.

Month	Comparison Site	*	1970		1971		1972		1973	
			Days	%	Days	%	Days	%	Days	%
Jan	Benton Harbor-St. Joseph Cook Plant	45	Recording started May 11, 1970		-		-		-	
					-		ND		ND	
Feb	Benton Harbor-St. Joseph Cook Plant	45			-		-		-	
					-		ND		ND	
Mar	Benton Harbor-St. Joseph Cook Plant	45			-		-		5/62	8.1
					-		ND		ND	
Apr	Benton Harbor-St. Joseph Cook Plant	55			-		-		-	
					-		ND		ND	
May	Benton Harbor-St. Joseph Cook Plant	60		3/42 7.1 14/42 33.3	-		-		-	
					-		-		ND	
Jun	Benton Harbor-St. Joseph Cook Plant	70		-/60 0.0 4/60 6.7	6/60 10.0 18/60 30.0	-			16/60 26.7 ND	
Jul	Benton Harbor-St. Joseph Cook Plant	80	-		-		-		-	
			-		-		-		ND	
Aug	Benton Harbor-St. Joseph Cook Plant	80	-		-		-		-	
			-		ND		-		-	
Sep	Benton Harbor-St. Joseph Cook Plant	80	ND		-		-		-	
			-		ND		-		-	
Oct	Benton Harbor-St. Joseph Cook Plant	65	-		6/62 9.7 ND		-		4/62 6.5 -	
			-		-		-		-	
Nov	Benton Harbor-St. Joseph Cook Plant	60	-		-		-		-	
			-		ND		ND		-	
Dec	Benton Harbor-St. Joseph Cook Plant	50	-		-		-		-	
			-		ND		-		-	

ND = no data

temperature variations, demonstrated by the close similarity between the Benton Harbor-St. Joseph and Cook station analysis.

5) The small difference of the average minimum and average maximum monthly lake water temperatures at stations of different depths indicates frequent mixing of the nearshore waters.

6) Recommended maximum lake water temperatures in effluents into the lake have on many occasions been exceeded.

Natural water temperature variations in the nearshore area are substantial and can happen within a day. It is important that aquatic biologists note that they and their rapidity exist, and also that there exist natural biological populations which are there because they can withstand these natural variations.

The addition of waste heat produced by a nuclear power plant is expected to be incorporated into the natural shore mixing process and this waste heat will most probably be reflected in a more frequent occurrence of temperature variation in the higher ranges of these variations.

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SURFICIAL SEDIMENT DISTRIBUTION OF THE NEARSHORE WATERS IN
SOUTHEASTERN LAKE MICHIGAN

Erwin Seibel, Robert E. Jensen and Christopher T. Carlson

Abstract. The sediment distribution in southeastern Lake Michigan showed the general trend from shore to be an increase in the standard deviation of the mean and a decrease in the mean particle size. However, this decrease in particle size is not uniform but rather spotty, indicating the presence of anomalies of finer within generally coarser areas and coarser materials within generally finer materials. There are present two zones of sedimentation distinguishable by the different means and standard deviations between the samples collected in water depth of 24 m or less or 24 m and deeper. This delineation of the sedimentation is thought to show two distinct sedimentary environments most probably associated with the region under the influence of the nearshore physical processes and those under the influence of these processes only during severe conditions. The sediment anomalies that are observed on the surficial sediment plots for the area and also on the profiles of the means and depth and standard deviation and depth are considered real and reflect the close spacing of the sampling grid. The need for closely spaced sampling grids is indicated by these anomalies if a true representation of the nearshore sediments is to be expected.

INTRODUCTION

A 175 square mile portion of southeastern Lake Michigan in the vicinity of the Donald C. Cook Nuclear Plant has been studied as part of the environmental monitoring program. The surficial sediment distribution was studied for an area (Fig. 1) extending from approximately 7 miles north of St. Joseph southward to

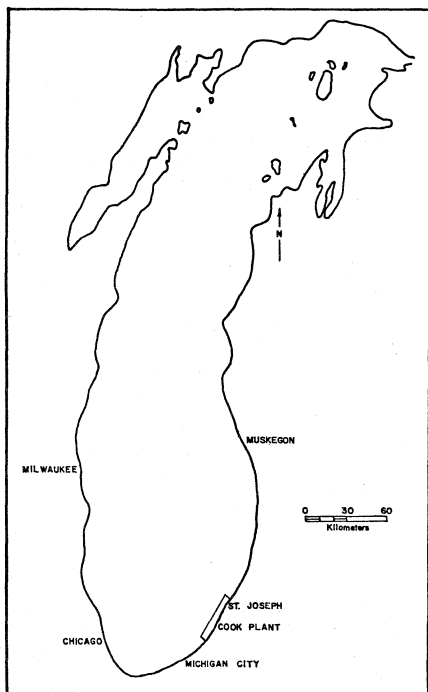


FIGURE 1. Location of study area in the vicinity of the Cook Plant.

about 1 mile south of the Warren Dunes State Park and extending to about 7 miles from shore.

The first comprehensive examination of the sediments of the Lake Michigan basin was that of Hough (1935). Subsequently Hulsey (1962), McGeary (1964), Davis and McGeary (1965) and Cote (1967) examined the sediments of southern Lake Michigan both on and off shore. Except for the work by Davis and McGeary (1965), the authors used widely spaced transects nearly perpendicular to shore in an effort to determine the characteristics of the surficial sediments. Davis and McGeary (1965) used more closely spaced transects close to shore to examine the sediments very close to shore and their relationship to the bar topography so pronounced and consistently present in this portion of Lake Michigan.

Cote (1967) developed a surficial sediment distribution map for the southern portion of Lake Michigan which was basically a refinement of the surficial distribution of Hough (1935). It was recognized in 1966, during the early years of the Cook study, that in order to determine the type of sediment present within the proximity of the plant a closely spaced grid was needed. Ayers and Huang (1967), working on a smaller portion of the present study area, determined surficial sediment distributions by means of visual field observations using a grid spaced at half-mile intervals out to 3 miles from shore. This led to the surficial sediment map shown in Figure 2. The works by Ayers and Hough (1964), Ayers (1967) Ayers and Huang (1967) and Cote (1967) have some basic shortcomings: they either used field identifications of sediment samples, or their grid was too widely spaced to distinguish the sediment distribution in small segments of the area being studied. While field identification of sediments may have the advantage of being immediately meaningful for comparison in the field, they are by nature subject to and depend on the expertise of the identifier. The widely

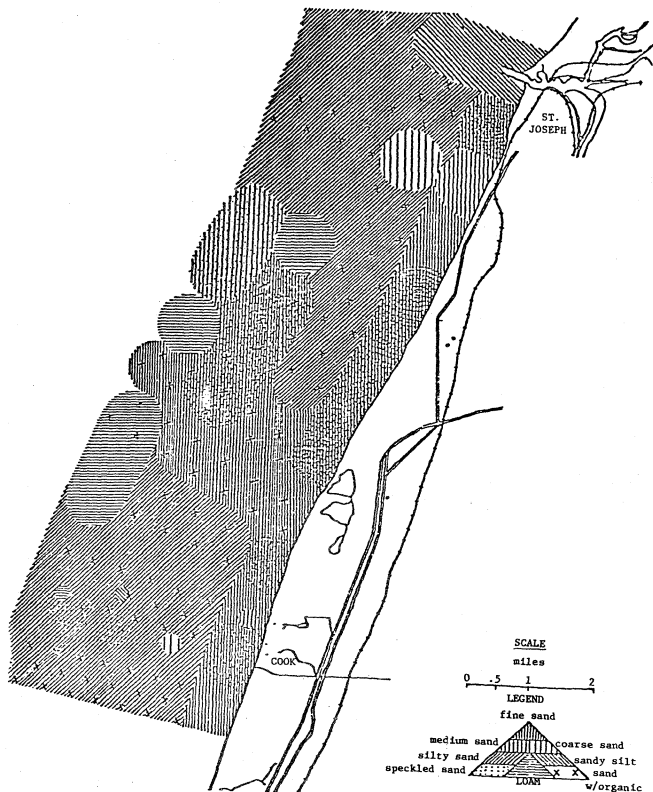


FIGURE 2. Surficial sediment map of portion of the study area done by Ayers and Huang in 1967 by field identification.

spaced sampling transect and grids used by Cote (1967), Ayers and Hough (1964) and Hough (1935) permit the compilation of sediment distribution maps, but because of the distances between transects local anomalies so critical in interpreting local conditions are naturally normalized and therefore for the most part not discernible. Avoiding the aforementioned pitfalls, the local distribution of sediments within the proximity of the plant and within the outflow area of the St. Joseph River were determined. The mapping process employed a 1 mile grid extending 7 miles from shore and an inner, closely spaced one-quarter mile grid in the proximity of the plant. The two transects in the vicinity of the St. Joseph River are more widely spaced. One transect goes directly westward from the channel and is 3 miles north of the transects that bound the 98 square mile area about the plant, and the northernmost transect is 7 miles north of the St. Joseph channel.

METHODS

Field samples were collected in September and October 1973 from the R/V MYSIS and the R/V MAPLE, using a ponar grab sampler which allows sampling of the upper 3 to 5 inches of the sediments. The samples were placed into plastic sealable bags capable of retaining the moisture of the sample. Duplicate samples were collected at each station, one for the grain size determination and the other for chemical analysis of the sediment. The sampling stations were spaced 1 mile apart with the distance between transects 1 mile. In a 2 mile by 2 mile inner grid the sampling points and the transects were spaced one quarter mile apart. The three transects in the St. Joseph River area were more widely spaced, as noted above. The three transects in the proximity of the St. Joseph River mouth were done in conjunction with a project designed to establish

relationships, if any, between sediment grain size, biota, and chemical sediment constituents and the presence of Cs^{137} nodes. Sample locations for portions of the area are shown in Figure 3.

Laboratory analysis of the samples was done by the standard sieve and pipette procedures with the preparation of the samples for sieving and pipetting performed as outlined by Royse (1970). Extreme care was taken to avoid the common difficulties of improper disaggregation and dispersion of the sediments before analysis. No samples had to be discarded due to these difficulties. Of the 172 samples collected during this study, 150 have been analyzed and are reported here.

The data are expressed in terms of the phi units as introduced by Krumbein (1938). Table 1 provides conversion scales of the phi units to microns and millimeters as well as a verbal description of the sediment between any two given phi units. The standard statistics of Folk, Inman, and Moment Measure were calculated by computer for each sample. In addition to calculating the statistics of each sample, the computer provided cumulative and histogram plots for each sample.

The interpretations and discussions on the data that follow are based on the moment measure statistics. Upchurch (1969) and Coakley and Beal (1972) point out that use of the moment measure statistics is the preferred method for deriving sediment textural parameters and is the most convenient method of routine sediment analysis. The moment measure is also extremely sensitive to the tails of a distribution and, perhaps most important, it is not subject to operator bias. The important consideration when using the moment measure is that it requires care and precision in preparing samples for analysis.

The computer was used extensively in reducing the volume of information

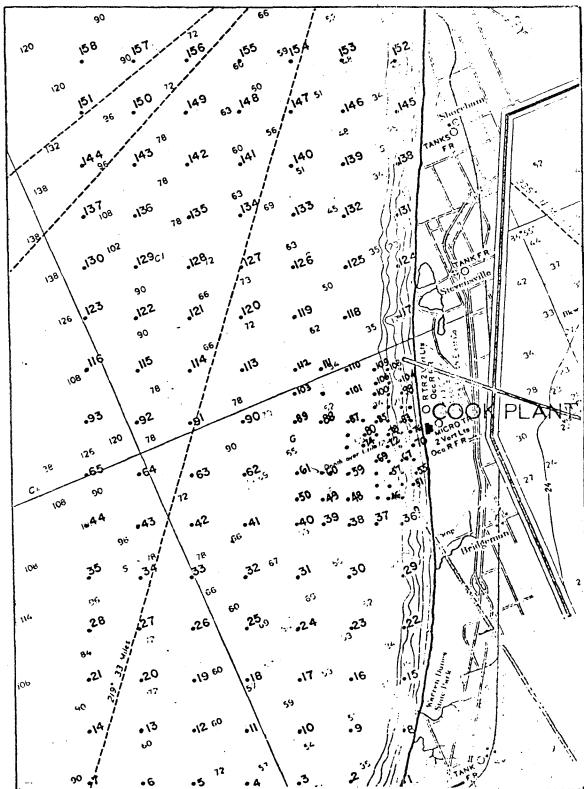


FIGURE 3. Sample stations in the study area to the transect 3 miles south of St. Joseph.

TABLE 1. Wentworth grade scale.

Phi unit*	Grade	mm	Microns	
-3		8.00	8000	GRAVEL
	Fine gravel			
-2		4.00	4000	
	Very fine gravel			SAND
-1		2.00	2000	
	Very coarse sand			
0		1.00	1000	SAND
	Coarse sand			
1		0.50	500	
	Medium sand			SAND
2		0.25	250	
	Fine sand			
3		0.125	125	SAND
	Very fine sand			
4		0.0625	62.5	
	Coarse silt			SILT
5		0.0313	31.3	
	Medium silt			
6		0.0156	15.6	SILT
	Fine silt			
7		0.0078	7.8	
	Very fine silt			CLAY
8		0.00391	3.91	
	Coarse clay			
9		0.00195	1.95	CLAY
	Medium clay			
10		0.00098	0.98	
	Fine clay			

*Phi unit = $-\log_2(\text{diameter of particle in mm})$

obtained from the sediment analysis. The plots of the percent distribution of a given size fraction were done by computer, using a plot routine which interprets between any given number of points. Four interpolation points were used in obtaining any one given data point on the percentage distribution plots. Scatter plots of the total data set were used in the analysis of the sediment samples with depth.

DISCUSSION

SEDIMENT DISTRIBUTION FOR THE LARGE SURVEY AREA

The large survey area sediment distribution was investigated to establish the character of the sediment in this portion of Lake Michigan and to determine if spacing of transects influences the distribution patterns obtained.

The large survey area is bounded by transects starting 2 miles south of Warren Dunes State Park and ending 7 miles north of the St. Joseph harbor. The transects from south to north are spaced at 1-mile intervals to 3 miles south of St. Joseph. After that there is a transect coming out from the St. Joseph River with the final one located 7 miles north. This transect spacing provides the transect density intended for making the comparison between sediment distribution in areas where the transects are more closely spaced with an area where the transect spacing is more widely spaced. The sampling stations on the transect for the large survey discussion are spaced at 1-mile intervals.

Descriptions and characteristics of the sediment samples collected over the large survey area are given in Table 2. Using the information provided in this tabulation as a base, the surficial sediment distributions maps presented in Figures 4, 5, 6, and 7 were constructed.

TABLE 2. Characteristics and description of the sediment by station for entire survey area.

Station	Date	Depth (m)	Percent of given fraction				Moment measure statistics			Folks textural description
			Gravel	Sand	Silt	Clay	Mean	Std. dev.		
2	9-21-73	14.0	0.00	98.95	1.05	0.00	2.300	0.676		moderately sorted sand
3		15.9	0.02	96.66	3.11	0.00	2.671	0.671		moderately sorted sand
4		17.4	0.07	98.69	1.04	0.00	1.944	0.711		moderately sorted sand
5		17.8	0.00	90.37	5.99	3.04	2.848	1.465		moderately poorly sorted sand
6		22.0	0.00	90.39	3.30	1.91	2.521	1.220		moderately poorly sorted sand
8		5.5	0.16	99.70	0.14	0.00	1.397	0.898		moderately poorly sorted sand
9		15.9	98.45	41.45	0.10	0.00	-1.233	1.745		poorly sorted sandy gravel
10		16.2	0.00	98.43	1.57	0.00	2.411	0.784		moderately poorly sorted sand
11		18.3	0.02	98.92	1.06	0.00	2.470	0.825		moderately poorly sorted sand
12		21.0	0.00	76.62	15.94	7.44	3.408	2.133		poorly sorted silty sand
13		23.2	0.00	56.02	33.77	10.21	4.596	1.979		poorly sorted silty sand
15		7.9	0.47	96.74	2.80	0.00	2.680	0.745		moderately sorted slightly gravelly sand
16		15.9	2.57	63.19	23.68	10.55	3.860	2.540		very poorly sorted slightly gravelly muddy sand
17		16.5	0.00	96.15	2.47	1.37	2.565	0.989		moderately sorted sand
18		18.9	0.18	95.11	3.15	1.56	2.477	1.135		moderately sorted slightly gravelly sand
19		21.3	0.00	63.34	25.30	11.36	4.132	2.335		very poorly sorted silty sand
20		24.1	0.07	75.79	16.59	7.56	3.289	2.296		very poorly sorted silty sand
22		8.2	0.42	96.04	3.54	0.00	2.808	0.684		moderately sorted slightly gravelly sand
23		15.9	0.01	99.14	0.84	0.00	2.208	0.637		moderately sorted sand
24		18.0	0.00	88.53	7.54	3.93	2.961	1.614		poorly sorted muddy sand
25		18.3	0.00	96.73	3.27	0.00	2.672	0.775		moderately poorly sorted sand
26		22.8	0.16	95.22	2.93	1.69	2.361	1.227		moderately sorted slightly gravelly sand
27		25.0	0.19	55.19	30.19	14.42	4.588	2.497		very poorly sorted slightly gravelly muddy sand
29		11.0	8.73	90.33	0.94	0.00	0.297	1.120		moderately poorly sorted gravelly sand
30		18.0	0.00	99.29	0.71	0.00	1.964	0.665		moderately sorted sand
31		18.3	0.00	87.79	8.31	3.90	3.007	1.598		poorly sorted silty sand
32		20.1	0.00	98.51	1.49	0.00	2.235	0.764		moderately sorted sand
33		22.6	0.00	98.51	1.49	0.00	-	-		moderately sorted sand
34		24.7	0.00	55.66	46.81	17.52	5.386	2.174		very poorly sorted sandy silt
36	10-22-73	9.1	0.15	96.82	3.03	0.00	2.864	0.604		moderately sorted slightly gravelly sand
37		13.7	0.00	99.00	5.00	0.00	0.744	0.674		moderately poorly sorted sand
38		16.5	0.00	90.68	0.52	0.00	1.896	0.724		moderately sorted sand
39		18.9	0.00	87.81	7.75	4.44	3.026	1.684		poorly sorted muddy sand
40		18.6	0.27	93.26	3.83	2.64	3.323	1.527		moderately poorly sorted slightly gravelly sand

TABLE 2 continued.

Station	Date	Depth (m)	Percent of given fraction				Moment measure statistics			Folks textural description
			Gravel	Sand	Silt	Clay	Mean	Std. dev.		
41	9-21-73	20.7	0.00	91.49	4.45	4.06	2.817	1.667	poorly sorted sand	
42		24.1	0.00	45.06	37.64	17.30	5.084	2.186	very poorly sorted sandy silt	
43		26.5	0.00	59.42	30.27	10.30	4.404	2.085	poorly sorted silty sand	
44		30.2	0.00	55.41	33.76	10.83	4.631	2.066	poorly sorted silty sand	
45	10-22-73	8.5	0.18	96.38	3.44	0.00	2.837	0.592	moderately sorted slight gravelly sand	
46		13.1	0.06	93.26	6.68	0.00	2.810	0.886	moderately poorly sorted sand	
47		18.6	0.06	99.47	0.47	0.00	1.466	0.537	moderately sorted sand	
48		18.9	0.00	71.30	20.13	8.57	3.796	2.167	poorly sorted silty sand	
50										
51		7.0	63.09	36.86	0.05	0.00	-1.203	0.978	moderately poorly sorted sandy gravel	
52		8.2	0.18	96.12	3.70	0.00	2.877	0.613	moderately sorted slightly gravelly sand	
53		12.2	0.00	96.86	2.20	0.94	2.477	0.942	moderately sorted sand	
54		13.4	0.04	95.91	4.05	0.00	2.720	0.823	moderately poorly sorted sand	
55										
56		6.7	0.00	97.57	2.43	0.00	2.586	0.533	moderately sorted sand	
57		8.5	0.07	95.46	4.47	0.00	2.908	0.637	moderately sorted sand	
58		16.4	0.00	98.94	1.06	0.00	2.049	0.685	moderately sorted sand	
59		17.7	0.25	90.65	6.09	3.01	2.698	1.538	poorly sorted slightly gravelly sand	
60		18.9	0.00	99.41	0.59	0.00	1.500	0.591	moderately sorted sand	
61	9-21-73	21.3	0.00	89.90	7.39	2.72	2.566	1.529	poorly sorted silty sand	
62		23.5	0.00	97.17	1.87	0.96	1.962	1.068	moderately sorted sand	
63									very poorly sorted slightly gravelly muddy sand	
64		25.9	1.33	51.67	37.21	9.79	4.309	2.307		
66	10-22-73	6.1	0.00	93.49	6.51	0.00	2.841	0.616	moderately sorted sand	
67		8.5	0.21	96.32	3.47	0.00	2.685	0.795	moderately sorted slightly gravelly sand	
68		11.9	0.07	94.14	5.79	0.00	2.677	0.872	moderately poorly sorted sand	
69		13.7	0.04	96.19	3.78	0.00	2.694	0.742	moderately sorted sand	
71		8.8	0.10	95.32	4.57	0.00	2.875	0.702	moderately sorted slightly gravelly sand	
72		12.8	5.50	93.41	1.09	0.00	0.711	1.028	moderately poorly sorted gravelly sand	
73		14.0	0.00	97.16	2.84	0.00	2.287	0.735	moderately sorted sand	
74		15.5	0.00	98.22	1.78	0.00	2.388	0.739	moderately sorted sand	
75		17.1	0.01	96.70	3.29	0.00	2.438	0.785	moderately poorly sorted sand	
76		5.8	0.34	98.28	1.38	0.00	1.904	0.931	moderately poorly sorted slightly gravelly sand	
77		9.1	0.09	94.75	5.16	0.00	2.945	0.634	moderately sorted sand	
78		13.1	0.02	95.21	3.10	1.67	2.302	1.286	moderately poorly sorted sand	

TABLE 2 continued.

Station	Date	Depth (m)	Percent of given fraction				Moment measure statistics		Folks textural description
			Gravel	Sand	Silt	Clay	Mean	Std. dev.	
79	10-22-73	14.0	0.00	92.37	7.63	0.00	2.864	0.833	moderately poorly sorted sand
80		15.8	3.16	96.67	0.17	0.00	0.807	0.902	moderately poorly sorted slightly gravelly sand
81		16.4	0.06	97.17	2.77	0.00	2.569	0.819	moderately poorly sorted sand
82		6.4	31.28	68.65	0.07	0.00	-0.547	1.132	poorly sorted sandy gravel
83		8.2	0.25	96.93	2.81	0.00	2.846	0.645	moderately sorted slightly gravelly sand
85		14.6	0.00	97.82	1.60	0.38	2.342	0.895	moderately sorted sand
86A		16.8	0.06	97.62	1.45	0.87	2.500	0.867	moderately sorted sand
86B		16.8	0.18	74.32	16.39	9.11	3.627	2.236	very poorly sorted slightly gravelly muddy sand
87		16.8	0.49	98.83	0.68	0.00	1.380	0.818	moderately poorly sorted slightly gravelly sand
88		18.0	0.00	73.50	17.13	9.38	3.626	2.253	very poorly sorted muddy sand
89		19.2	0.00	99.32	0.68	0.00	1.960	0.625	moderately sorted sand
90	9-21-73	21.6	0.00	91.45	8.55	0.00	2.259	1.463	poorly sorted sand
91		24.1	0.00	26.03	53.03	20.94	5.676	2.191	very poorly sorted sandy silt
92		28.3	0.00	56.38	33.15	10.47	4.541	1.979	poorly sorted silty sand
94	10-22-73	4.9	0.00	98.26	1.74	0.00	2.532	0.511	moderately sorted sand
94A		4.9	0.19	99.52	0.29	0.00	1.114	0.780	moderately sorted slightly gravelly sand
95		7.9	0.01	96.85	3.14	0.00	2.872	0.574	moderately sorted sand
96		12.2	0.00	81.99	11.49	6.52	3.332	1.945	poorly sorted muddy sand
98		7.3	0.08	97.32	2.61	0.00	2.822	0.560	moderately sorted sand
99		11.3	0.00	96.82	3.18	0.00	2.561	0.767	moderately sorted sand
100		13.4	0.00	98.73	1.27	0.00	2.268	0.634	moderately sorted sand
101		16.4	0.00	97.04	2.96	0.00	2.475	0.783	moderately poorly sorted sand
102		18.0	0.00	99.88	0.12	0.00	1.466	0.476	moderately sorted sand
103		19.8	0.00	95.96	4.04	0.00	2.547	0.833	moderately poorly sorted sand
104		7.6	0.00	97.64	2.36	0.00	2.814	0.544	moderately sorted sand
105		11.9	0.01	96.24	3.75	0.00	2.665	0.738	moderately sorted sand
106		12.2	0.06	99.70	0.25	0.00	1.505	0.593	moderately sorted sand
107		6.7	15.62	83.96	0.43	0.00	0.070	1.196	poorly sorted gravelly sand
108		8.2	0.06	97.21	2.73	0.00	2.882	0.588	moderately sorted sand
109		12.2	0.06	97.21	2.73	0.00	-	-	moderately sorted sand
110		16.2	0.00	73.17	17.20	9.63	3.807	2.183	poorly sorted muddy sand
112		19.5	0.00	98.50	1.50	0.00	2.331	0.717	moderately sorted sand
114	9-21-73	24.4	0.00	95.84	2.33	1.83	2.255	1.242	moderately sorted sand
115		27.7	0.00	62.47	28.69	8.84	4.138	2.029	poorly sorted silty sand

TABLE 2 continued.

Station	Date	Depth (m)	Percent of given fraction				Moment measure statistics		Folks textural description
			Gravel	Sand	Silt	Clay	Mean	Std. dev.	
117	9-21-73	8.2	5.03	91.86	3.11	0.00	1.872	1.436	poorly sorted gravelly sand
118		14.9	0.00	95.93	4.07	0.00	2.768	0.665	moderately sorted sand
119		19.2	0.00	99.08	0.92	0.00	1.974	0.648	moderately sorted sand
120		21.3	0.00	84.21	9.61	6.18	3.042	2.031	poorly sorted muddy sand
121		24.4	0.00	44.99	38.92	16.10	5.078	2.256	very poorly sorted sandy silt
122	28.3	0.00	70.33	22.16	7.51	3.790	2.067	poorly sorted silty sand	
124		4.9	0.00	99.34	0.66	0.00	1.927	0.652	moderately sorted sand
125		13.7	0.00	95.04	3.36	1.60	2.620	1.085	moderately sorted sand
126		18.3	0.13	93.70	6.17	0.00	1.889	1.014	moderately poorly sorted slightly gravelly sand
127		20.1	0.00	95.02	4.98	0.00	2.656	0.810	moderately poorly sorted sand
129		31.1	0.00	82.03	11.19	6.77	3.030	2.113	poorly sorted muddy sand
131	10-22-73	5.5	7.70	92.17	0.13	0.00	0.844	1.115	poorly sorted gravelly sand
132		11.9	0.06	99.67	0.27	0.00	2.009	0.684	moderately sorted sand
133		18.3	21.00	78.49	0.51	0.00	-0.209	1.252	poorly sorted gravelly sand
134		21.9	8.40	48.74	25.38	17.48	4.001	3.290	very poorly sorted gravelly muddy sand
135		25.6	0.00	52.19	28.62	19.19	4.822	2.488	very poorly sorted muddy sand
136	29.3	0.00	69.53	18.87	11.61	3.958	2.297	very poorly sorted muddy sand	
138		7.0	0.22	97.27	2.51	0.00	2.300	0.817	moderately poorly sorted slightly gravelly sand
139		14.6	0.00	99.83	0.17	0.00	1.541	0.582	moderately sorted sand
140		16.4	0.06	99.82	0.12	0.00	1.691	0.642	moderately sorted sand
141		20.1	22.61	76.85	0.54	0.00	-0.154	1.290	poorly sorted gravelly sand
142		25.6	0.00	77.42	12.88	9.70	3.188	2.488	very poorly sorted muddy sand
143	27.4	0.15	77.82	13.72	8.31	3.277	2.295	very poorly sorted slightly gravelly muddy sand	
145		4.9	1.55	98.37	0.09	0.00	0.610	0.707	moderately sorted slightly gravelly sand
146		12.8	0.13	99.62	0.26	0.00	2.077	0.649	moderately sorted slightly gravelly sand
147		18.3	6.86	81.25	8.55	3.34	1.584	2.254	poorly sorted gravelly muddy sand
148		20.1	0.01	96.42	3.57	0.00	2.676	0.708	moderately sorted sand
149		23.8	0.24	92.58	7.18	0.00	2.146	1.075	poorly sorted slightly gravelly sand
150	27.4	0.00	66.22	24.13	9.65	4.249	2.129	poorly sorted silty sand	
152	10-21-73	9.1	0.00	99.12	0.88	0.00	2.518	0.619	moderately sorted sand
153	10-22-73	16.2	0.00	86.37	6.64	4.98	3.040	1.708	poorly sorted muddy sand
154		19.8	1.21	97.18	1.61	0.00	0.931	0.876	moderately sorted slightly gravelly sand
155		21.3	0.02	98.28	1.70	0.00	2.542	0.621	moderately sorted sand
156		25.6	0.00	83.45	10.14	6.41	2.940	2.060	poorly sorted muddy sand

TABLE 2 continued.

Station	Date	Depth (m)	Percent of given fraction				Moment measure statistics		Folke textural description
			Gravel	Sand	Silt	Clay	Mean	Std. dev.	
157	10-22-73	29.6	0.00	49.36	30.58	20.07	5.121	2.459	very poorly sorted sandy mud
158		35.0	0.05	63.99	25.25	10.71	4.333	1.930	poorly sorted silty sand
159	10-02-73	9.1	0.42	98.85	0.73	0.00	2.054	0.724	moderately sorted slightly gravelly sand
160		15.2	0.02	99.11	0.87	0.00	2.205	0.675	moderately sorted sand
161		20.1	0.02	94.79	5.19	0.00	2.856	0.777	moderately poorly sorted sand
162		23.2	0.00	92.62	3.35	4.03	2.689	1.584	poorly sorted sand
163		25.9	0.00	64.00	19.88	16.12	4.263	2.666	very poorly sorted muddy sand
164		29.0	0.00	56.39	25.75	17.86	4.742	2.533	very poorly muddy sand
165		33.5	0.03	46.61	37.75	15.61	5.067	2.141	very poorly sorted sandy silt
166	10-01-73	16.4	0.00	95.20	2.83	1.97	2.521	1.228	moderately sorted sand
167		19.8	0.00	92.75	3.65	3.60	2.817	1.520	moderately poorly sorted sand
168		21.3	29.49	69.87	0.64	0.00	-0.083	1.372	poorly sorted gravelly sand
169		25.6	0.00	78.92	10.71	10.38	3.354	2.441	very poorly sorted muddy sand
170		28.0	0.00	76.76	13.50	9.75	3.349	2.446	very poorly sorted muddy sand
171		31.4	1.33	79.96	10.99	7.72	3.208	2.215	poorly sorted slightly gravelly muddy sand
172		34.4	0.03	75.79	16.33	7.86	3.681	2.109	poorly sorted silty sand
173		36.6	0.00	48.60	37.58	13.82	4.903	2.057	poorly sorted sandy silt

- = no values computed

% Gravel In Surficial Sediments Off Southeastern Lake Michigan Benton Harbor-St. Joseph

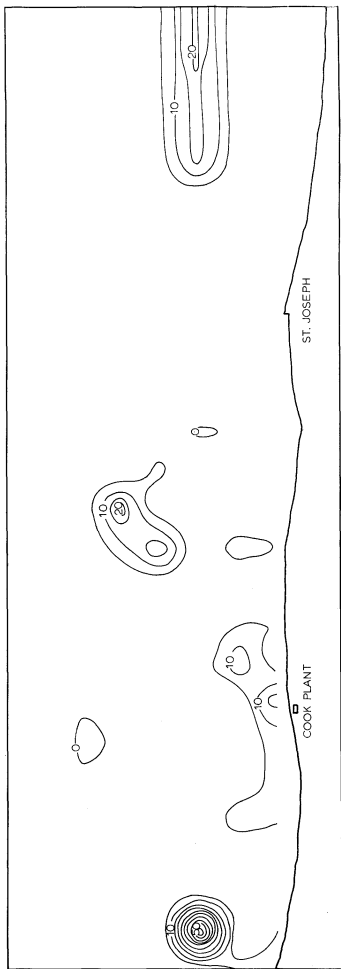


FIGURE 4. Percentage of gravel in surficial sediments. Large survey area. Dots indicate sampling stations.

% Sand In Surficial Sediments Off Southeastern Lake Michigan Benton Harbor-St. Joseph

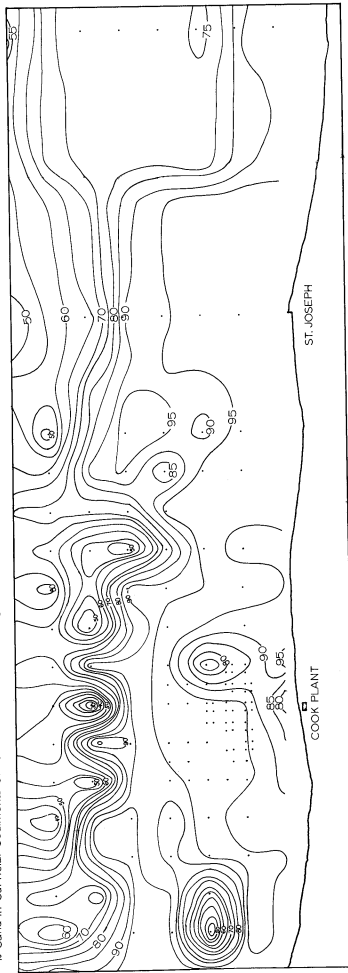


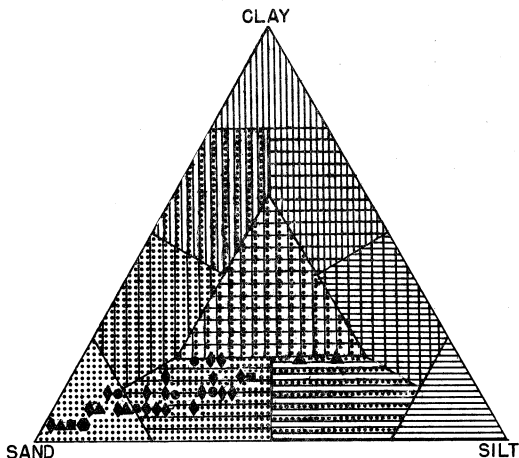
FIGURE 5. Percentage of sand in surficial sediments. Large survey area. Dots indicate sampling stations.

Percentage of gravel in surficial sediments

Gravel is not found in large amounts in the survey area, and when found it is in isolated patches with the maximum amount in a pocket about 1 mile south of the Warren Dunes State Park and about 2 miles from shore (see Fig. 4). Gravel pockets are also present in the proximity of the plant where the 5% gravel contour extends southward for about 3 miles, generally less than 1 mile from shore. The 10% and 15% gravel contours are deflected southward from the transect emanating from the plant area itself. Another patch of gravel is present between 5 and 6 miles south of St. Joseph harbor and between 4 and 5 miles north of the plant, between 2 and 5 miles from shore. The last pocket of gravel is observed as a finger extending southward between 1 and 3 miles from shore north of the St. Joseph harbor. This last point must be viewed with some caution, as it is determined using a single data point. All the other gravel pockets are considered real, while the northernmost fingerlike extension may actually be the result of one data point.

Percentage of sand in surficial sediments

The distribution of the sand (Fig. 5) in the large survey area is complex. The 95% contour for sand, which starts about 3 1/2 miles north of St. Joseph, extends southward for the entire length of the survey area. The fact that this contour line comes so close to shore reflects the possible influence of the long-shore currents on the sand distribution in the area bounded by the 95% sand contour. In the proximity of the Cook Plant a pocket exists 1 mile north of the plant, extending 3 miles from shore where the percentage of sand is reduced. A similar situation is present in the area south of Warren Dunes where the sand fraction is less. The pocket near Warren Dunes can be explained by the presence of the gravel patch in that location. The general trend for the percent sand



NUMBER OF SAMPLES
FALLING AT THAT POINT

- ◆ - ONE
- - TWO
- - THREE
- ▲ - FOUR
- - FIVE

SOILS

- ||||| CLAY
- ||||| SILTY CLAY
- ||||| SANDY CLAY
- ||||| SAND
- ||||| SILTY SAND
- ||||| CLAYEY SAND
- ||||| SILT
- ||||| CLAYEY SILT
- ||||| SANDY SILT
- ||||| LOAM

FIGURE 6. Triangular plot of percent sand-silt-clay.

contours is a decreasing percentage of sand in the offshore direction. In those locations where the percentage of sand is reduced, the gravel, silt or clay sized materials show a greater predominance. Most of the samples collected fall within a region dominated by the sand mean diameter. The triangular plot of the percent of sand-silt-clay (Fig. 6) shows that the majority of samples texturally are either sand or silty sand with only small fractions of the samples falling in other than those two textural categories.

A contrast exists between the complexities of the contours south of St. Joseph and those about and north of St. Joseph. The detail of the distribution of the sand north and south of the plant and the lack of detail in the general vicinity of the St. Joseph River are considered the first indication that spacing of the sampling influences the determination of anomalies of the sediment distribution in the nearshore.

Percentage of silt in surficial sediments

Examination of the silt distribution contour map (Fig. 7) reveals a close relationship between the sand and silt distribution patterns. Silt-sized particles are most evident in the lakeward portion of the survey, with pockets of higher fractions of up to 50% silt in locations where the sand was shown to be least. Silt pockets with up to 15% silt are noted 1 mile north of the plant site and in water about 2 miles from shore. This location shows an unusual sediment pattern. In the same shoreward location of the silt pocket, gravel percentage was about 10%. Sand in this general location was about 75%. This kind of pattern is suggestive of the patchiness found in this nearshore zone, where by going only a short distance one experiences a quick shift from the coarser to the finer and then again to the coarser-sized materials. The ridge-like projections on the silt-sized distribution contours reflect the same ridge-like

% Silt in Surficial Sediments Off Southeastern Lake Michigan Benton Harbor-St. Joseph

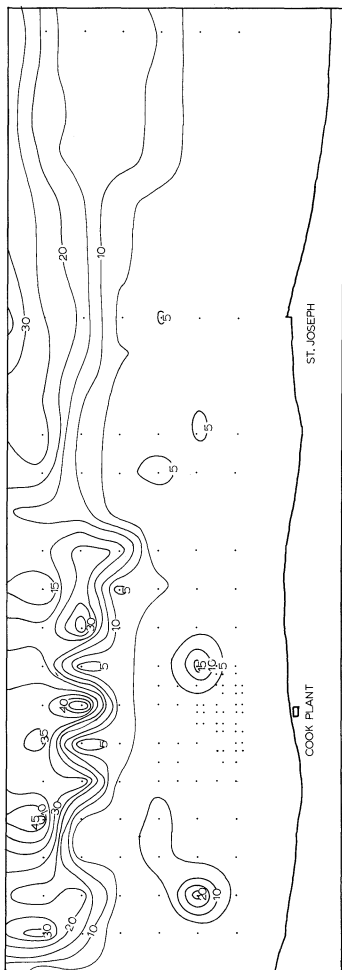


FIGURE 7. Percentage of silt in surficial sediments. Large survey area. Dots indicate sampling stations.

projections found in the sand contour map. These ridge-like projections break up areas of sand and finer material concentrations. Why one finds the projections is not known. The silt distribution again shows the marked difference in detail between the area about the plant location and that about the St. Joseph River area. This increased precision in the plant's proximity can be attributed again to the frequency of transects.

Percentage of clay in surficial sediments

Clay-sized particles are not extensively present for the large survey area. They are found almost entirely in the area 4 miles from shore and lakeward. The clay distribution (Fig. 8) reflects the general pattern already established by the contours of the sand and silt percentages.

Mean grain size diameter of the surficial sediments

The contour plot of the mean grain size pattern in phi units shown in Figure 9 reveals, as expected, the influence on the mean grain size of the percentage of occurrence of a particular grain size fraction in a given sample. The mean grain size diameters range from -1.0 to 5.0 phi units. The silt-sized mean occurs most lakeward in two large areas. The first of these silt areas is south of the plant site and 5 miles from shore; the second is also located about 5 miles from shore and extends from north of St. Joseph to about 5 miles south of the St. Joseph harbor. A medium sand mean grain size is located north of the St. Joseph harbor and may reflect the high percentage of gravel found in the same location. This particular patch is considered a possible rather than probable real point. The remaining area shows a very fine and fine sand pattern with lakeward projections of medium sand. These lakeward arms are extensive and in three locations: 1) The southernmost (near Warren Dunes) is in the area

% Clay In Surficial Sediments Off Southeastern Lake Michigan Benton Harbor - St. Joseph

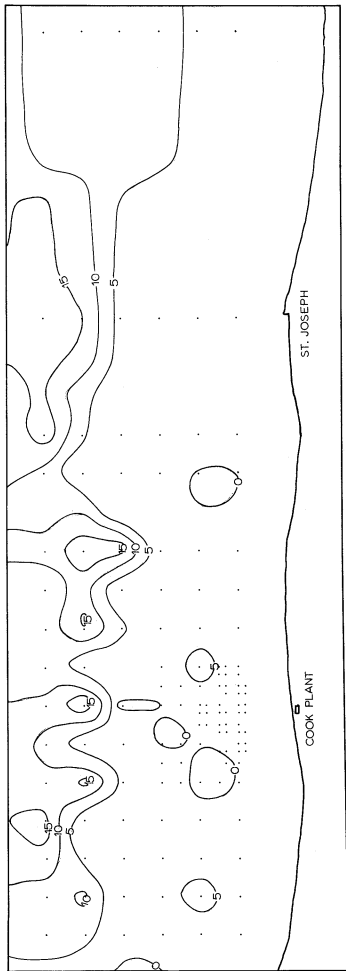


FIGURE 8. Percentage of clay in surficial sediments. Large survey area. Dots indicate sampling stations.

Mean Grain Size Diameter Of Surficial Sediments Off Southeastern Lake Michigan

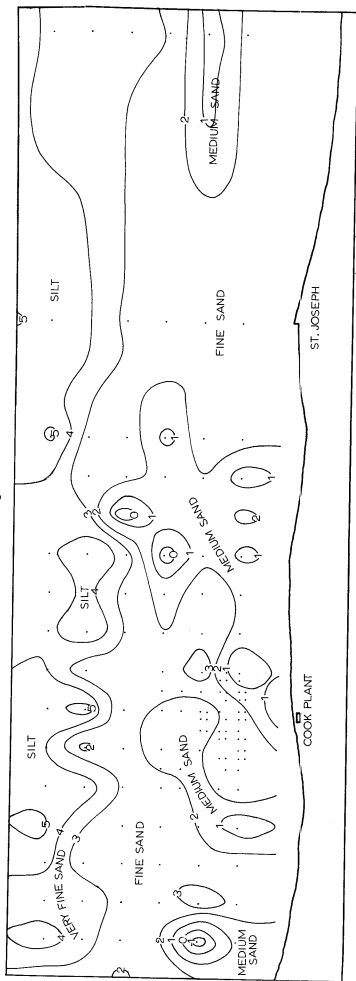


FIGURE 9. Mean grain size diameters of the surficial sediments. Large survey area. Dots indicate sampling stations.

already described as having a large concentration of gravel; it shows the coarsest mean phi unit (-1.0), 2) The second arm is located south of the Cook Plant and appears simply to be a continuation of 3) the arm located to the north of the plant. These lakeward arms (shown on Figure 8) extend as far as 4 miles offshore and are located principally in the area where the grid is detailed enough to permit distinguishing the patterns. These anomalies are again absent to the north near St. Joseph, and again are most probably the result of the spacing of the transects.

It is difficult to explain these lakeward projections, but several mechanisms for their formulation are possible. Davis and Fox (1972) have suggested that rip currents are present in the nearshore zone. These currents are capable of transporting material lakeward wherever channels are cut into the nearshore bar system. The bar systems for southeastern Lake Michigan are concentrated within a half mile or less from shore; these projections, however, extend much farther from shore than can be explained by rip current systems. However, if the longshore currents are deflected lakeward by these rip currents it is possible that the sand moving along the shore is deflected lakeward, and these projections then could reflect this lakeward motion of littoral material. Aerial photographs of the area often depict fingers of turbid water extending offshore. These turbid fingers are most likely sediment laden waters. The eventual deposition of the sediment from these turbid water regions could be what the sediment distribution picture presented here reflects. Hands (1970) indicates that irregular fingers of turbid water extending to 1 km both from shore and along shore were frequent features of Lake Michigan's western shore. This finger-like turbid water is also noticeable on most sets of aerial photographs of the eastern shore of Lake Michigan investigated by the senior author.

Another possible explanation of these lakeward arms is the winnowing out of finer material and transporting of this material lakeward or north or south. There seems to be no evidence of that process, but this should not be ruled out. The third possibility is that the fine sand found elsewhere in the nearshore is not being deposited where these lakeward medium sand arms are present. For example, the area about the St. Joseph River mouth is depicted as being composed of fine sand, while both to the north and the south medium sand projections are observed. It is possible that the fine sands are being deposited where shown, and only in isolated instances reach over the general distribution of medium sand. No one speculation is considered adequate at this time to explain the mean size distribution patterns exhibited.

A meaningful procedure in further examination of the mean grain size distribution and the percentage of a given sediment size is to examine a north-south line a given distance from shore, and to follow this line northward. This reveals a patchiness in the sediment distribution which is reflected in all of the data discussed thus far. The patchiness in the distribution of the sediments in the nearshore is reflected most accurately in the area where the transects are spaced at 1-mile intervals and the sampling grid is spaced at regular distances from shore. The patchiness is least pronounced in the northernmost portion of the study area, where the transects are spaced more widely even though the grid points are again spaced 1 mile apart going lakeward. If the purpose of the survey is to detail the actual sediment distribution of the nearshore zone of sedimentation, this distribution pattern suggests to the authors the need to use a regular closely spaced sampling grid.

Standard deviation of the mean grain size (diameters)

The standard deviation as used here is a measure of sorting of the samples.

Sorting is a means of establishing whether the sediment is made up of a narrow range of sediment grain sizes or a wide range. The poorer the sorting or the greater the standard deviation, the larger the range of grain size diameters found in a given sample. Table 3 provides the standard deviations and their relationship to sorting. A well-sorted sample would most probably have a large

TABLE 3. Standard deviation of the mean as a measure of sorting.

Standard deviation (phi units)	Sorting
0.0 - 0.5	Well sorted
0.5 - 1.0	Moderately sorted
1.0 - 2.0	Poorly sorted
2.0 - 4.0	Very poorly sorted

percentage of its sample in one given phi unit, while a poorly sorted sample would have many phi units represented in some fraction of 100 in its sample with no one fraction large. Although this hard and fast rule does not hold universally, it can be used as a simple verbal explanation of the sorting criteria.

Figure 10 represents the sorting for the large survey area whose contours are shown on Figure 11. Using a 0.5 phi unit interval for contouring the standard deviation of the mean of the sediments, it is observed that the sediments found closest to shore have the best sorting with the lakeward sediments increasing in the standard deviation and hence having poorer sorting. The sorting contours provide no surprises, since they reflect the percentage occurrence of the various grain size fractions. The sorting is poorest in those

Standard Deviation Of The Mean Grain Size Of Surficial Sediments Off Southeastern Lake Michigan

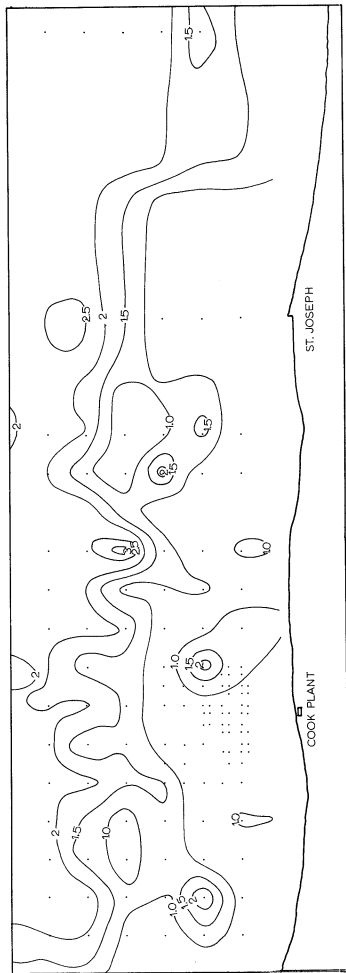


FIGURE 10. Standard deviation of the mean grain size diameters. Large survey area. Dots indicate sampling stations.

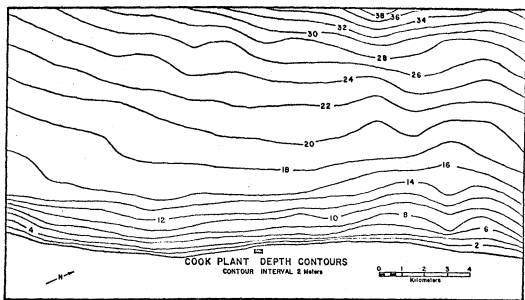


FIGURE 11. Contour map of the Lake Michigan bottom in the vicinity of the Cook Plant.

locations where the percent composition of the sediments was found to be more heterogeneous and is best where the sediments were found to be most homogeneous. The sorting of the sediment is best near shore except for three locations. In the proximity of the St. Joseph Harbor, the sorting of the sediment is poorer much closer to shore than elsewhere in the study area. In addition to this general area, locations showing poorer sorting close to shore are found 1 mile north of the plant site about 2 miles from shore where the mean grain size is about 3.0 phi units, and a location near Warren Dunes State Park. As in the previous discussions of the percent size fraction and the mean grain size distributions, the standard deviation contours are much more irregular in the southern more closely spaced transect pattern than they are to the north in the more widely spaced transect area. This irregularity is influenced by the spacing of the grid points as much as by the physical processes.

Several generalizations can be made about the standard deviation of the mean grain size distribution. It is accurate to state that in general the standard deviation increases lakeward showing the best sorting near the shore. It also reflects closely the distribution patterns of the individual sediment size distributions. The standard deviation, as the sediment percent maps and the mean grain size distribution map, shows the occurrence of pockets of materials more poorly sorted within areas of better sorting. The pocketing of sedimentation is least well discernible in the standard deviation patterns.

SEDIMENT DISTRIBUTION FOR THE INNER SURVEY AREA

The inner survey is defined as that closely spaced grid about the Cook Nuclear Plant. This portion of the study is intended to establish the sediment types in an area of approximately 7 square miles. The "horizontal" distance between stations in the inner survey varies. The outer transects and those

farthest north and south have their sampling points spaced at 1-mile intervals. The stations closer to the plant and closer to shore are spaced at quarter-mile or half-mile intervals. The sampling stations are shown in Figure 12.

Percentage of gravel in the surficial sediment

As in the larger grid, gravel (Fig. 13) is not a significant fraction in the surficial sediments. Gravel is found in three localities close to shore in water 1/4 to 1/2 mile from shore at a distance of about 1 mile south of the plant and about 1/4 mile and 1 1/4 miles north of the centerline of the plant. The maximum percentage of gravel in the north is less than 20%, while to the south it is less than 50%. The gravel pocket to the south shows a southward orientation of the finest contour line. Figure 14, which presents the depth contours for the inner survey, suggests a possible reason for the southward tapering. The pockets of gravel are situated in locations where the energy input from waves could be substantial. The very northern pocket, 1 1/4 miles north of the plant, is located at the edge of a ridge-like topographic feature suggesting an area of convergence of refraction rays and hence increased wave energy there. The southernmost pocket also is situated at the northern rim of a ridge-like feature permitting energy concentration in these locations. The pocket about 1/4 mile north of the plant again falls on a less pronounced ridge feature. The southward tapering could also be explained by the influence of the littoral current on the motion of material. The littoral current in this portion of the lake is predominantly to the south. For these pockets to exist, it is likely that the littoral transport of material coupled with the concentration of wave energy in these areas has resulted in motion of the finer sediments southward and retention of the gravel in those localities.

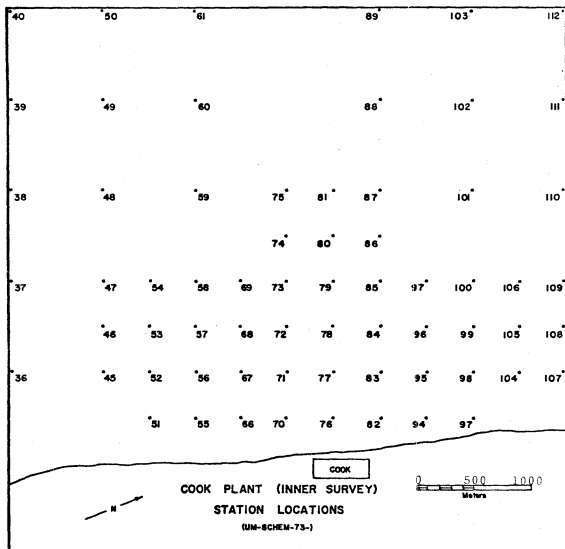


FIGURE 12. Sampling stations for sediment analysis in the inner survey area.

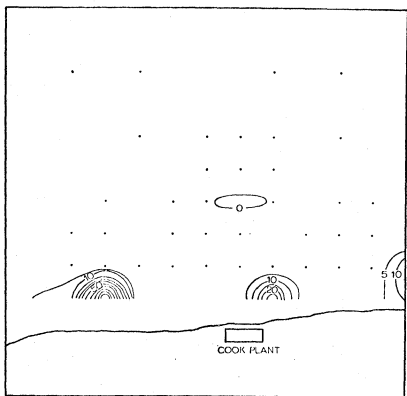


FIGURE 13. Percentage of gravel in the surficial sediments. Inner survey area. Dots indicate sampling stations.

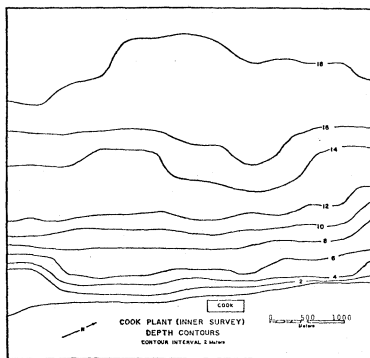


FIGURE 14. Depth contours for the inner survey area.

Percentage of sand in surficial sediments

The sand distribution shown in Figure 15 depicts the area as being predominantly within the sand fraction of the sediment spectrum. The sand percentile of 95 dominates the contour map. However, the sand fraction decreases percentage-wise in several locations. To the south of the Cook Plant site (in the same location that gravel was found to be present in up to 50%), the sand fraction declines and then increases southward. About 1/4 mile north of the plant, the 95% contour is observed surrounding areas of lesser sand fractions. The pocket closest to shore is attributable to the larger percentage of gravel found there and noted above. As one goes lakeward on the 1/4-mile transect north of the plant, one observes that the lower percentage of sand shifts to the north and then returns south again to be in line with the original 1/4-mile spot from the plant. The decreased sand is a result of the increased silt and clay fractions. It is noteworthy that the location of the plant serves as a convenient demarcation between similar size distribution patterns. In the more lakeward sections of the inner survey, the sand fraction of 95% surrounds again a stretch of lake bottom with finer materials within its bounds.

Two possible criteria contribute to the explanation of the distribution pattern of the inner survey. The sediment size distribution and the bottom topography show a similarity. The percentage of gravel increase in the south of the plant portion was attributed in part to the presence of a ridge-like topographic feature with a poorly developed gentle valley next to it. The increased amount of sand southward there suggests that the sand is in motion with the gravel retained and the sand deposited farther to the south. The most lakeward distribution of the sand mixed with the finer silt and clay appears again to be controlled by bottom topography. The sand contours in the lakeward portion approximate the depth contours. The plateau-like feature in the center

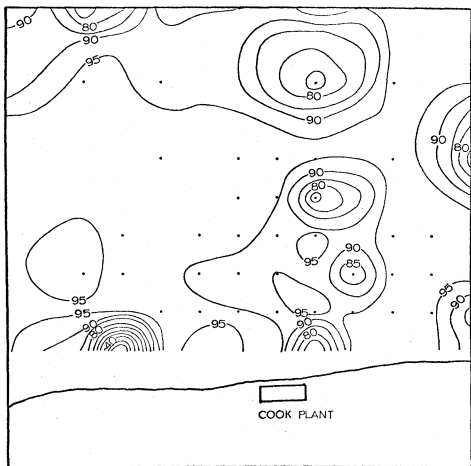


FIGURE 15. Percentage of sand in the surficial sediments. Inner survey area. Dots indicate sampling stations.

and northern segments of the depth contours finds smaller fraction of sand as does the valley-like feature in the southernmost corner of the inner survey. The deposition of finer materials incorporated into the sand in this gentler topographic regime is plausible because wave energy is less in this region.

Explanation of the contours of the sand distribution to the north of the plant is again slanted toward the influence of the topography coupled with the wave action. A valley which extends from just north of the plant lakeward, becoming most pronounced in the 12- through 16-m depth contours, suggests an explanation of the finer material enclosed by the southward and lakeward trending 95% contour interval. In the approximate location where the 16-m contour is most valley-like, the sediment becomes finest, showing sand to be about 75% of the total quantity. The southward trend of the 95% contour of sand is probably due to the influence of the predominant southward littoral drift in the lake at this portion of the shoreline. The finer sediments are then interpreted as being a reflection of the valley with the greater percentages of sand on sides and crests of the valley sides and extending southward, due to the current regime.

Percentage of silt in surficial sediments

Silt is a minor constituent in the inner survey, showing itself in those locations where sand is mixed with the silt. The silt (Fig. 16) is found in small quantities ranging from 0 to 15% of the total sediment fraction. The presence of the silt must be linked to the presence of the sand and the explanation for its pocket-like locations is as noted above.

Percentage of clay in surficial sediments

Clay (Fig. 17) is found in percentages of generally less than 5% for the inner survey grid. The presence of clay-sized sediment in this active inner

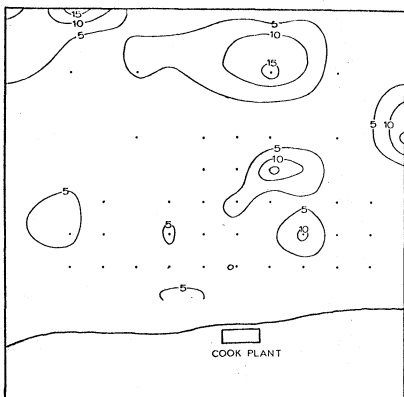


FIGURE 16. Percentage of silt in the surficial sediments. Inner survey area. Dots indicate sampling stations.

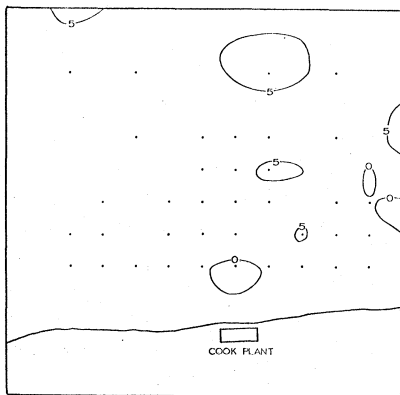


FIGURE 17. Percentage of clay in the surficial sediments. Inner survey area. Dots indicate sampling stations.

survey area should not be expected in large quantities, because if disturbed it would be lost from the area and transported into deeper waters. The presence of the clay-sized particles in what can be protected valley-like depressions is, however, plausible.

Mean grain size diameter of surficial sediments and the standard deviation of the mean grain size

The mean grain size diameters found for the inner survey grid are shown in Figure 18. The distribution ranges from a -1.0 to 3.0 phi units. These size units make the mean for the entire area fall entirely within the sand range. This mean size range is the reflection of the large percentage of sand found in this area. The influence that the silt fractions and the gravel fractions play on the mean grain size are obvious from the patchiness of the mean grain size contours. Where gravel or silt were present the phi units were smaller and larger respectively. The contours for the mean grain size clearly indicate that the predominant sand present in the area is a fine to medium sand interspersed with gravel and silt pockets.

The standard deviation of the mean grain size (Fig. 19) has a range of from 1.0 to 2.0 phi units, indicating that for most of the samples the sorting in this survey area is moderate. Only in those locations which showed silt and clay does the sorting become poor. It is noteworthy that the sorting does not simply become poorer as one goes away from the shore, but that instead the sorting reflects the sand percentage contours interlaced with the silt and clay contours. For the nearshore processes that are at work in the nearshore zone, this seems a more reasonable pattern than the generalization that too often crops up--that as one goes lakeward or offshore the sorting becomes poorer. That statement may be valid if one averages out the inshore anomalies, but certainly it is not valid when one considers the inshore zone as a single unit.

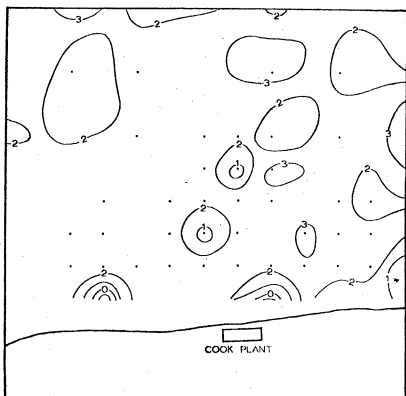


FIGURE 18. Mean grain size diameters of surficial sediments. Inner survey area. Dots indicate sampling stations.

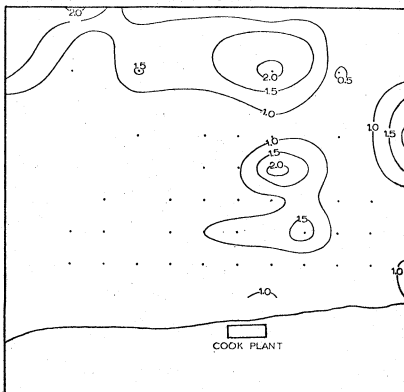


FIGURE 19. Standard deviation of the mean grain size diameters. Inner survey area. Dots indicate sampling stations.

SEDIMENT DISTRIBUTION ALONG TRANSECTS

The discussion on the distribution of the sediments to this point has been centered on the percentage distribution and averages for the entire study area. Of interest and importance also is the distribution of the sediment along transect profiles. For this discussion the 17 transects that extend to about 7 miles from shore will be used.

In Figure 20, the depth, the mean of the sample collected at the given depth, and the standard deviation of the mean are plotted for each transect. The location of the transects is shown in Figure 3.

In general, the expected occurs. The mean grain size of the sample decreases lakeward and the standard deviation of the mean increases. The increase in the standard deviation shows poorer sorting of the sediment with depth and is generally associated with a larger range in particle sizes within a sample. The spread between the mean and the standard deviation of the mean increases lakeward; this too is interpreted as showing poorer sorting and greater particle size diversity than in the shallower stations. The divergence between the mean and the standard deviation starts to become most pronounced for most of the profiles at about 2 to 3 miles from shore. The profiles show the anomalies in the sediments as one goes lakeward. The sediments generally become finer lakeward. However, that change is not uniform. Profile 2 clearly shows the location of the high-percent gravel area near Warren Dunes State Park, about 1 mile from shore. The profiles near the Cook Plant (Profiles 6 through 9) have a greater irregularity in the mean and standard deviation for stations to 2 miles from shore than do other profiles. This irregularity is observed because of the closer spacing of the grid stations in the area about the plant, and gives further credence to the hypothesis that anomalies in sedimentation are present

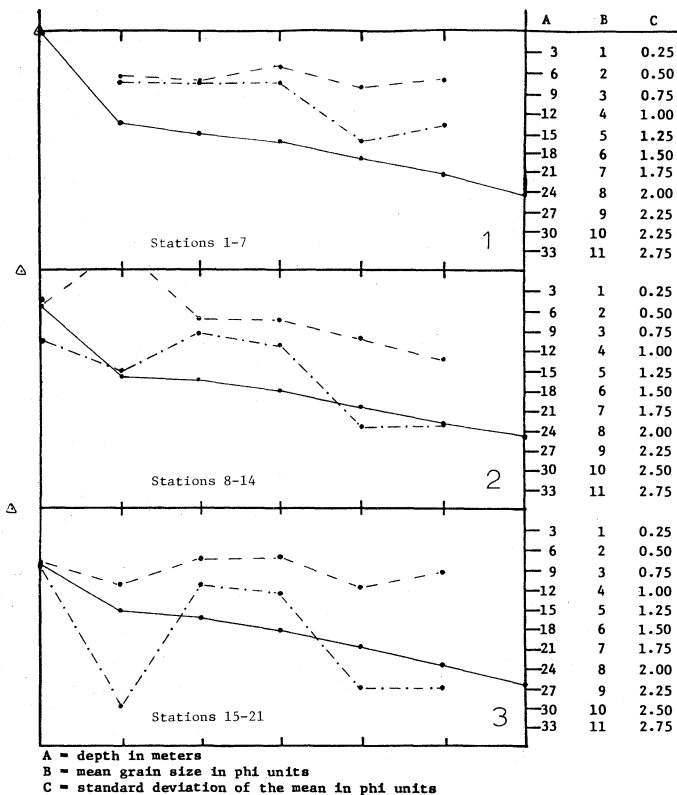


FIGURE 20. Variation of depth, mean grain size and standard deviation with distance offshore for transects in southeastern Lake Michigan between St. Joseph-Benton Harbor and the southern edge of Warren Dunes State Park.

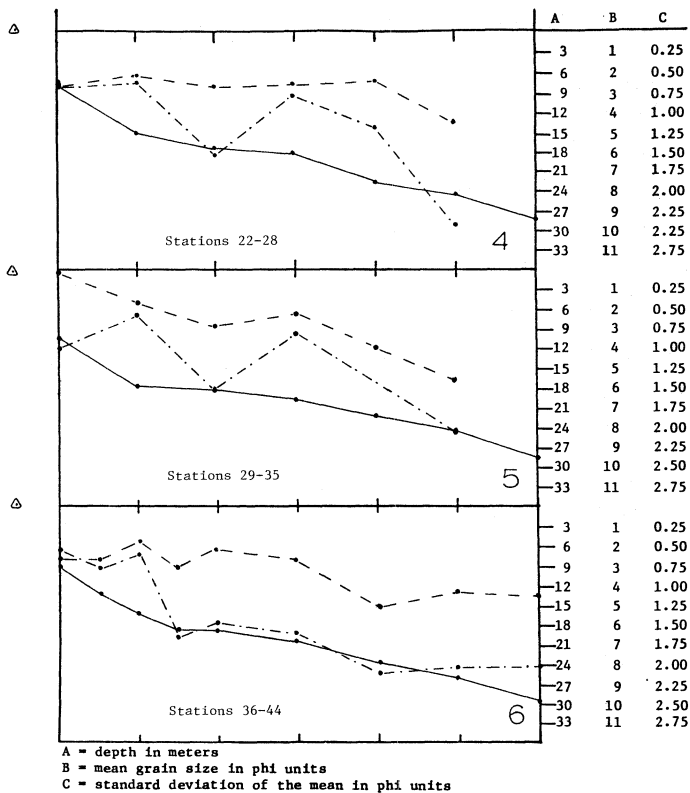


FIGURE 20 continued.

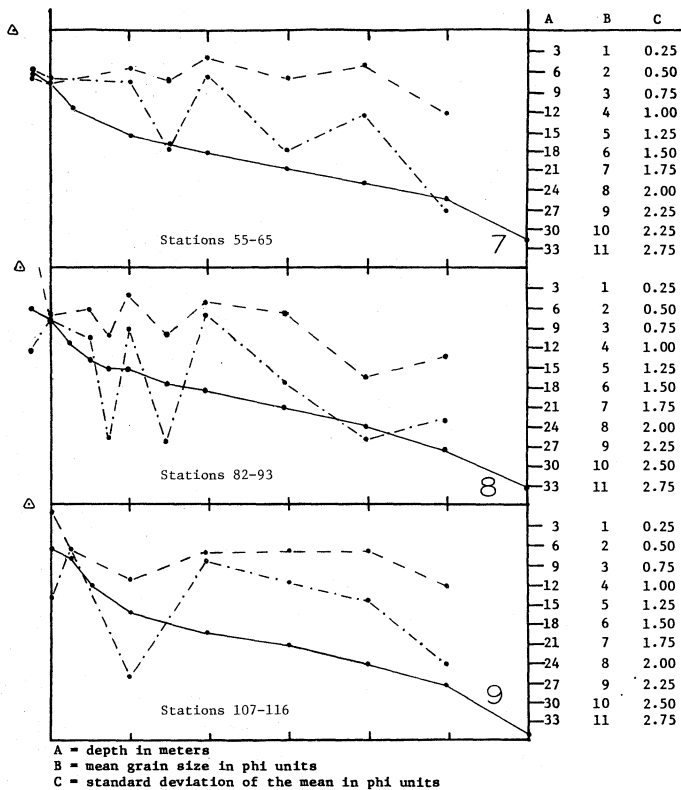


FIGURE 20 continued.

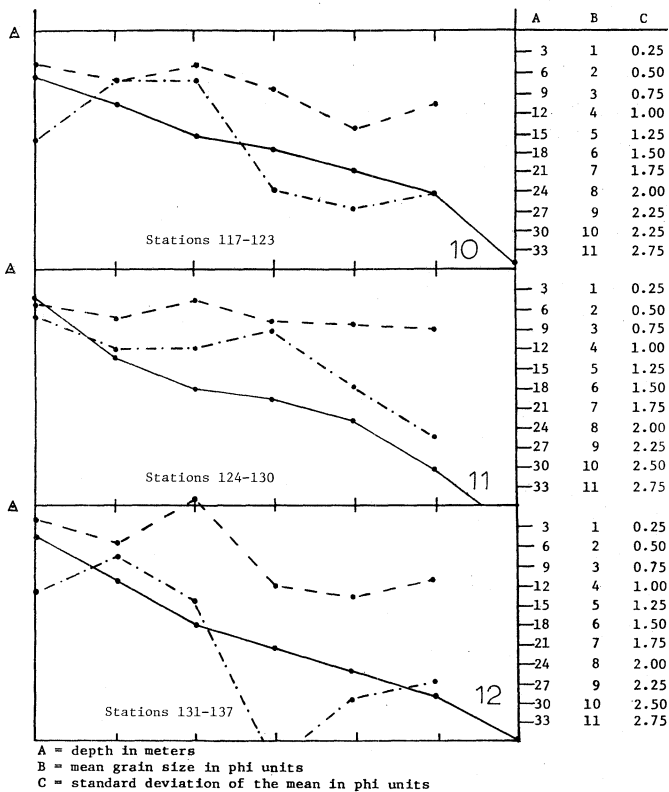


FIGURE 20 continued.

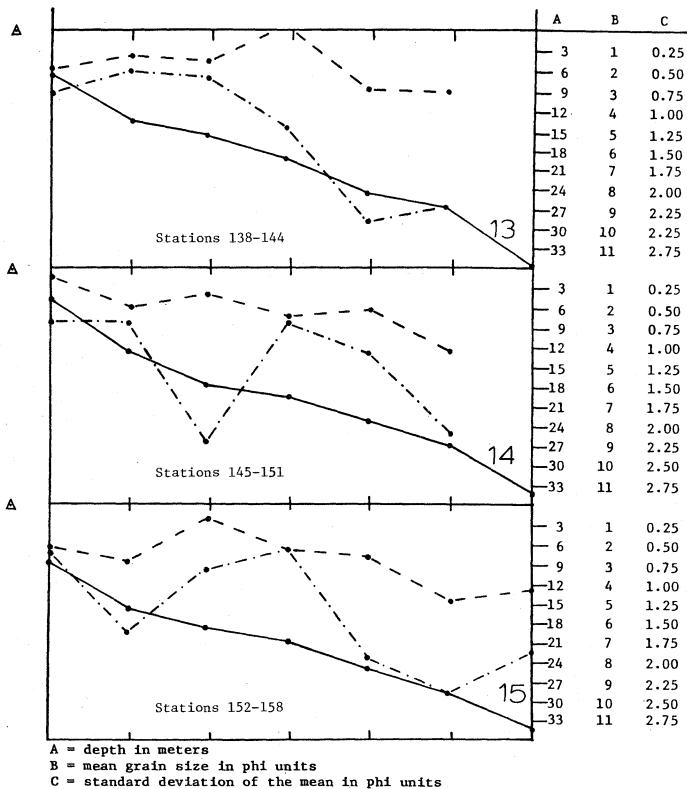


FIGURE 20 continued.

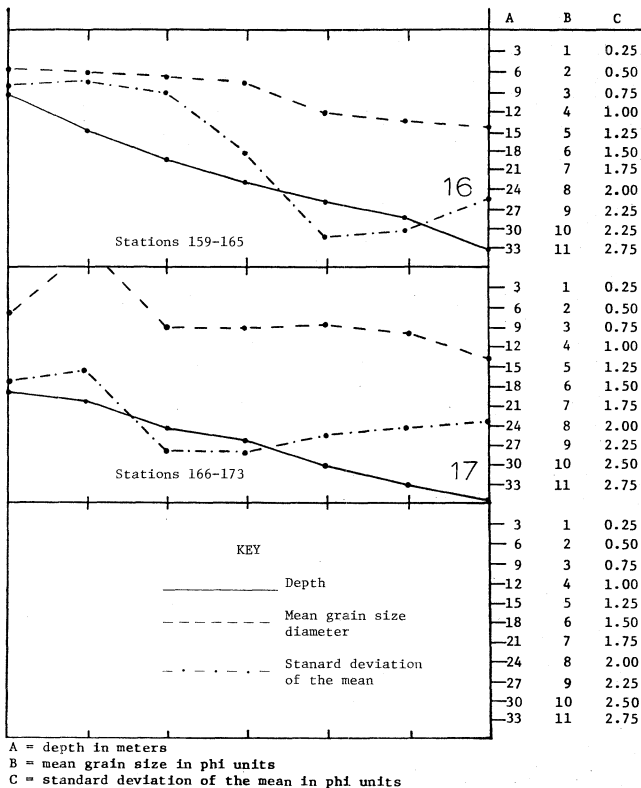


FIGURE 20 continued.

and can be observed only with sufficiently close spacing of the sampling grid. The irregularity in sediment distribution decreases lakeward, since the increase in depth effectively reduces the influence of the major physical forces that influence the bottom, particularly waves and longshore currents.

SURFICIAL SEDIMENT DEPTH ZONES

It has been shown in the previous sections that the general character of the sediment in the survey area is a decreasing grain size diameter in the lakeward direction. The decrease in grain size diameter is not uniform nor predictable but rather exhibits local anomalies of finer materials in coarser areas and coarser materials in generally finer areas of sedimentation. The above is at best a generalization, and upon closer examination of the sediment data distinct depth zones become distinguishable.

Table 4, a summary of the general character of the sediments in five depth strata, shows a marked difference in both the mean grain size and the standard deviation of the sediments found in depths greater than 24 m from those in depths less than 24 m. The five depth strata which were defined were: less

TABLE 4. General statistics of the samples by depth range. The number of samples, depth range, mean of the samples, and standard deviations of the mean are given.

Strata	Depth range (m)	Number of samples	Mean (phi units)	Standard deviation (phi units)
1	less than 12	35	2.14	0.80
2	12-18	41	2.37	1.01
3	18-24	43	2.43	1.33
4	24-30	23	3.99	2.16
5	greater than 30	6	3.70	1.88

than 12 m, 12-18 m, 18-24 m, 24-30 m, and greater than 30 m. This strata division was chosen as the clearest zonation of sediments by mean grain size and standard deviations. Other depth ranges were investigated prior to the strata selected. The depth ranges of 3, 4, 5, 8 and 12 m were examined in addition to the strata selected, and all showed a marked division of the sediments in this portion of the lake at about 24-m depth.

Although an apparent break in the sediment is indicated by data in Table 4, it becomes clearer when one examines the plot of the mean grain size diameters of all samples against the depth at which the samples were taken (Fig. 21). The break between sediments with mean grain size diameters of less than 3.0 phi and those with a greater-than-3.0 phi diameter occurs at about the 24-m depth. The plot of the standard deviation of the means against the depth (Fig. 22) also shows that the division of the sediments occurs at about the 24-m depth. At that depth, the data set is divided into samples generally above and below a standard deviation of the mean of 1.8 phi. Figure 23, the plot of all the means against their respective standard deviations, clearly shows that two distinct clusters of sediments are present, those that have a standard deviation less than 1.8 phi and mean less than 3.0 phi and those greater than the latter. Although the data plotted in Figure 3 clearly show the division, Figures 21 and 22 may leave some doubt as to exactly where the differentiation line should be drawn. Therefore we examined the data set for a possible transition zone between the two distinctly different depth regimes of sedimentation. The plot of the number of samples that occur for each of the means and standard deviations (Fig. 24) indicates in the standard deviation histogram that there is a zone present between the sediments of less than 1.8 phi standard deviation and those greater. This is represented by the node in the proximity of the 1.5 phi standard deviation.

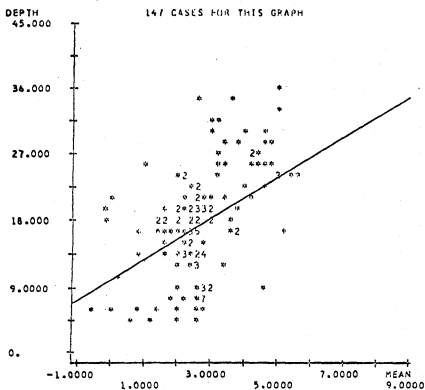


FIGURE 21. Plot of depth vs mean for the samples in phi units.

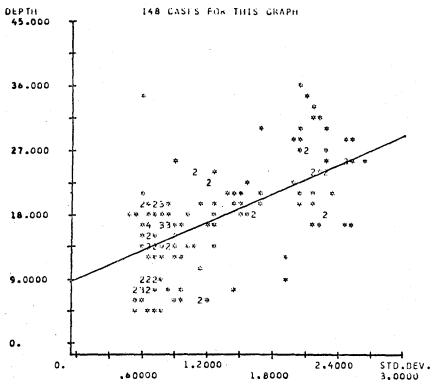


FIGURE 22. Plot of depth vs standard deviation of the mean grain size diameter for the analyzed samples. Depth in meters. Standard deviation in phi units.

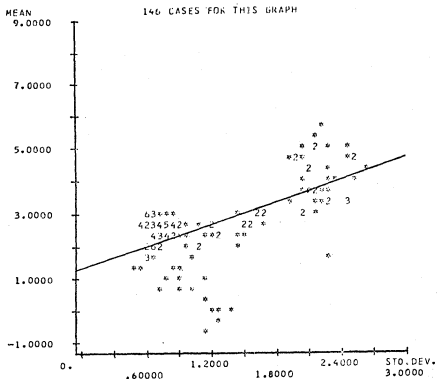


FIGURE 23. Plot of the means vs standard deviation of the mean in phi units.

HISTOGRAM/FREQUENCIES		HISTOGRAM/FREQUENCIES	
MIDPOINT	COUNT FOR MEAN	MIDPOINT	COUNT FOR STD.DEV.
-1.0000	0 +	0.	0 +
-.50000	1 +X	.15000	0 +
0.	4 +XX	.30000	0 +
.50000	3 +XX	.45000	2 +XX
1.-0000	4 +XXX	.60000	29 +XXXXXXXXXXXXXXXXXXXXXXXXXXXX
1.5000	10 +XXXXX	.75000	31 +XXXXXXXXXXXXXXXXXXXXXXXXXXXX
2.0000	17 +XXXXXXX	.90000	12 +XXXXXXXXXXXX
2.5000	44 +XXXXXXXXXXXXXXXXXXXXXXX	1.0500	9 +XXXXXXXXXXXX
3.0000	29 +XXXXXXXXXXXXXXXXXXXX	1.2000	9 +XXXXXXXXXX
3.5000	9 +XXXXX	1.3500	3 +XXX
4.0000	9 +XXXXX	1.5000	7 +XXXXXX
4.5000	9 +XXXXX	1.6500	6 +XXXXXX
5.0000	6 +XXX	1.8000	0 +
5.5000	2 +X	1.9500	4 +XXX
6.0000	0 +	2.1000	14 +XXXXXXXXXXXX
6.5000	0 +	2.2500	12 +XXXXXXXXXXXX
7.0000	0 +	2.4000	4 +XXX
7.5000	0 +	2.5500	5 +XXXX
8.0000	0 +	2.7000	1 +X
8.5000	0 +	2.8500	0 +
9.0000	0 +	3.0000	0 +
2 < -1.0000 149 (.50000) = INTERVAL WIDTH		1 > 3.0000 149 (.15000) = INTERVAL WIDTH	

Stratum 1: Depth less than 12 m

Of the samples found in stratum 1, all but one have a mean less than 3.0 phi and all but one have a standard deviation less than 1.8 phi. Most of the samples in this strata have a standard deviation of less than 1.0 phi, indicating that the first stratum is moderately sorted and the mean of the samples falls within the broad category of sand. Figures 25 through 27 show the data for this stratum graphically.

Stratum 2: Depth between 12-18 m

This stratum exhibits the features of stratum 1 in that most of the points for this depth range fall below a mean of 3.0 phi and a standard deviation of 1.8 phi. However, more data points fall above those limits in this stratum than in the previous stratum. This is not an unexpected event when one compares the manner in which the sediments show themselves on the surficial sediment maps where fine and coarse anomalies are found to occur. Figures 28 through 30 show the data from stratum 2 graphically. As in stratum 1, a single node exists for the standard deviation histogram. This node occurs between .6 and .9 phi units. The node in stratum 1 occurred between 0.6 and 0.75 phi. This upward shift in the node is interpreted as indicating a shift in the sorting of this depth range from moderate to poor sorting. The scatter of the points in stratum 2 is greater than that in stratum 1 (Figs. 29 and 30), but the samples are again clustered within narrow limits.

Stratum 3: Depth between 18-24 m

This depth stratum has been interpreted as a transition zone between the sediments found in water depths greater than 24 m and those in water less than 24 m. This transition zone hypothesis is given support by the increased scatter of the sediment samples found in this stratum. Figure 31, rather than exhibiting

HISTOGRAM/FREQUENCIES		STRATUM = 1	HISTOGRAM/FREQUENCIES		STRATUM = 1
MIDPOINT	COUNT FOR MEAN	(EACH X =1)	MIDPOINT	COUNT FOR STD.DEV.	(EACH X =1)
-1.0000	0 +		0.	0 +	
-.50000	1 +X		.15000	0 +	
0.	1 +X		.30000	0 +	
.50000	2 +XX		.45000	1 +X	
1.0000	2 +XX		.60000	13 +XXXXXXXXXXXX	
1.5000	1 +X		.75000	11 +XXXXXXXXXXXX	
2.0000	5 +XXXXX		.90000	3 +XXX	
2.5000	8 +XXXXXXXXX		1.0500	3 +XXX	
3.0000	13 +XXXXXXXXXXXX		1.2000	2 +XX	
3.5000	0 +		1.3500	0 +	
4.0000	0 +		1.5000	1 +X	
4.5000	1 +X		1.6500	0 +	
5.0000	0 +		1.8000	0 +	
5.5000	0 +		1.9500	1 +X	
6.0000	0 +		2.1000	0 +	
6.5000	0 +		2.2500	0 +	
7.0000	0 +		2.4000	0 +	
7.5000	0 +		2.5500	0 +	
8.0000	0 +		2.7000	0 +	
8.5000	0 +		2.8500	0 +	
9.0000	0 +		3.0000	0 +	
TOTAL	1 < -1.0000 35 (.50000 = INTERVAL WIDTH)		TOTAL	35 (.15000 = INTERVAL WIDTH)	

FIGURE 25. Number of samples in stratum 1 that occur for each of the means and standard deviations. Means and standard deviations in phi units.

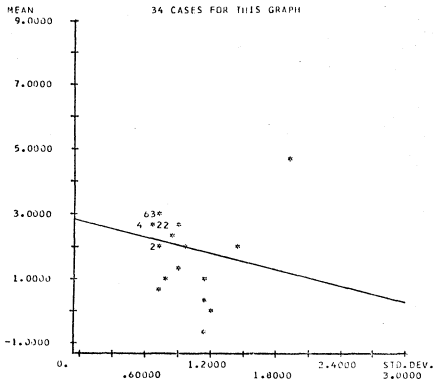


FIGURE 26. Plot of the means vs standard deviations of the means in phi units of samples in stratum 1.

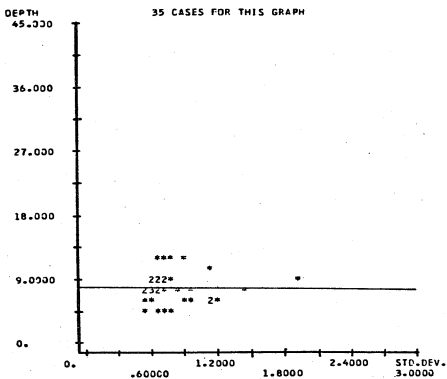
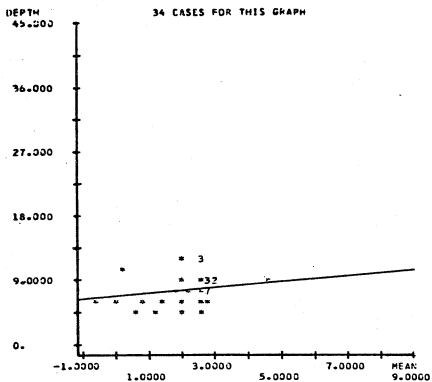


FIGURE 27. Plot of the means and standard deviations against depth (M) of samples in stratum 1.

HISTOGRAM/FREQUENCIES STRATUM = 2			HISTOGRAM/FREQUENCIES STRATUM = 2		
MIDPOINT	COUNT FOR MEAN	(EACH X =1)	MIDPOINT	COUNT FOR STD.DEV.	(EACH X =1)
-1.0000	0 +		0.	0 +	
-.50000	0 +		.15000	0 +	
0.	0 +		.30000	0 +	
.50000	1 +X		.45000	0 +	
1.0000	1 +X		.60000	9 +XXXXXXXXXX	
1.5000	4 +XXXX		.75000	14 +XXXXXXXXXXXXXXX	
2.0000	6 +XXXXXX		.90000	6 +XXXXXX	
2.5000	20 +XXXXXXXXXXXXXXXXXXXX		1.0500	3 +XXX	
3.0000	3 +XXX		1.2000	2 +XX	
3.5000	2 +XX		1.3500	1 +X	
4.0000	2 +XX		1.5000	1 +X	
4.5000	0 +		1.6500	0 +	
5.0000	1 +X		1.8000	0 +	
5.5000	0 +		1.9500	1 +X	
6.0000	0 +		2.1000	0 +	
6.5000	0 +		2.2500	2 +XX	
7.0000	0 +		2.4000	1 +X	
7.5000	0 +		2.5500	1 +X	
8.0000	0 +		2.7000	0 +	
8.5000	0 +		2.8500	0 +	
9.0000	0 +		3.0000	0 +	
TOTAL	1 < -1.0000		TOTAL	41 (.15000	= INTERVAL WIDTH)
	41 (.50000	= INTERVAL WIDTH)			

FIGURE 28. Number of samples in stratum 2 that occur for each of the means and standard deviations. Means and standard deviations in phi units.

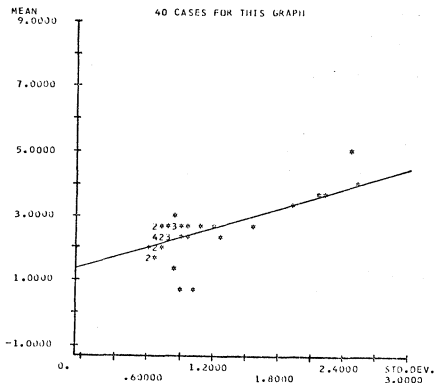


FIGURE 29. Plot of the means vs standard deviation of the means in phi units of samples in stratum 2.

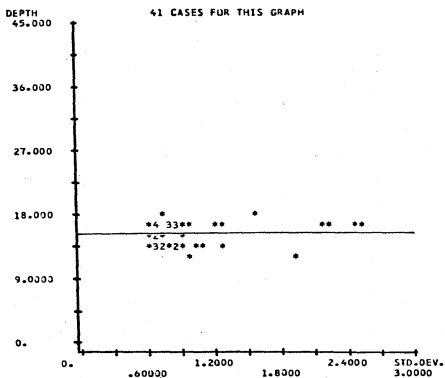
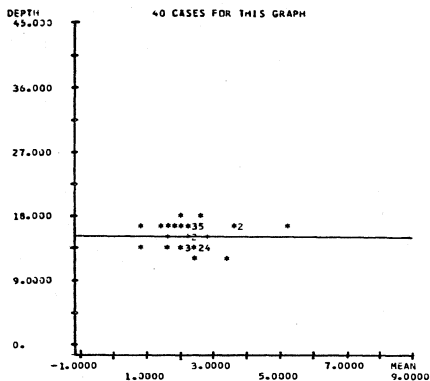


FIGURE 30. Plots of the means and stard deviations against depth (M) of samples in stratum 2.

one node for the standard deviation histogram, exhibits several with one of the nodes occurring above 1.8 phi units. Figure 32, a plot of the mean of the samples against the standard deviation of the means, also shows a greater scatter for this depth region than for the shallower stratum. We can consider this stratum to be a transition zone on the basis of the scatter of the data for this zone, but the placement of the boundary between the deeper and shallower stations can still occur at the upper bounds of this zone because for the most part the mean of the samples in this zone fall below 3.0 phi (Fig. 33) and also the standard deviations of the zone fall for the most part below the 1.8 phi units.

Stratum 4: Depth between 24-30 m

The previous strata showed that for the most part the means and standard deviations within each stratum fell below 3.0 and 1.8 phi respectively. This stratum clearly shows a shift of both the means and the standard deviations above those limits (Figs. 34 through 36). The plot of the mean against standard deviations of the mean shows the data points clustered above the intersection of the 3.0-1.8 phi lines, with only three data points not meeting this criterion (Fig. 35).

Stratum 5: Depth greater than 30 m

The data for this stratum are shown graphically in Figures 37 through 39. There is a limitation to the interpretation of the data in this stratum, as the sample number is much smaller than for the other strata, however, the general conclusion reached about the break of the region studied into two sediment zones is upheld. The standard deviation of the means falls within the criterion, yet the means of the samples do not. The average mean of the samples and the average standard deviation of the means meet the established criterion.

HISTOGRAM/FREQUENCIES STRATUM = 3			HISTOGRAM/FREQUENCIES STRATUM = 3		
MIDPOINT	COUNT FOR MEAN	(EACH X =1)	MIDPOINT	COUNT FOR STD.DEV.	(EACH X =1)
-1.0000	0 +		0.	0 +	
-1.50000	0 +		.15000	0 +	
0.	3 +XXX		.30000	0 +	
.50000	0 +		.45000	1 +X	
1.0000	0 +		.60000	6 +XXXXXX	
1.5000	5 +XXXXX		.75000	6 +XXXXXX	
2.0000	6 +XXXXXX		.90000	2 +XX	
2.5000	14 +XXXXXXXXXXXXXX		1.0500	3 +XXX	
3.0000	9 +XXXXXXXXXXXX		1.2000	4 +XXXX	
3.5000	2 +XX		1.3500	2 +XX	
4.0000	3 +XXX		1.5000	5 +XXXXX	
4.5000	1 +X		1.6500	5 +XXXXX	
5.0000	0 +		1.8000	0 +	
5.5000	0 +		1.9500	1 +X	
6.0000	0 +		2.1000	4 +XXXX	
6.5000	0 +		2.2500	2 +XX	
7.0000	0 +		2.4000	1 +X	
7.5000	0 +		2.5500	0 +	
8.0000	0 +		2.7000	0 +	
8.5000	0 +		2.8500	0 +	
9.0000	0 +		3.0000	0 +	
TOTAL	43 (.50000 = INTERVAL WIDTH)		TOTAL	1 > 3.0000 43 (.15000 = INTERVAL WIDTH)	

FIGURE 31. Number of samples in stratum 3 that occur for each of the means and standard deviations. Means and standard deviations in phi units.

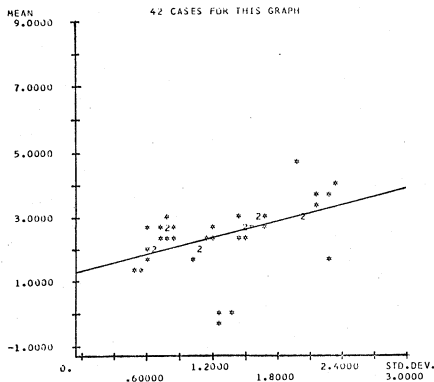


FIGURE 32. Plot of the means vs standard deviation of the means in phi units of samples in stratum 3.

HISTOGRAM/FREQUENCIES STRATUM = 4			HISTOGRAM/FREQUENCIES STRATUM = 4		
MIDPOINT	COUNT FOR MEAN	(EACH X = 1)	MIDPOINT	COUNT FOR STD.DEV.	(EACH X = 1)
-1.0000	0 +		0.	0 +	
-.50000	0 +		.15000	0 +	
0.	0 +		.30000	0 +	
.50000	0 +		.45000	0 +	
1.0000	1 +X		.60000	0 +	
1.5000	0 +		.75000	0 +	
2.0000	0 +		.90000	1 +X	
2.5000	1 +X		1.0500	0 +	
3.0000	2 +XX		1.2000	1 +X	
3.5000	4 +XXXX		1.3500	0 +	
4.0000	4 +XXXX		1.5000	0 +	
4.5000	6 +XXXXXX		1.6500	1 +X	
5.0000	3 +XXX		1.8000	0 +	
5.5000	2 +XX		1.9500	1 +X	
6.0000	0 +		2.1000	5 +XXXXXX	
6.5000	0 +		2.2500	7 +XXXXXXXX	
7.0000	0 +		2.4000	2 +XX	
7.5000	0 +		2.5500	4 +XXXX	
8.0000	0 +		2.7000	1 +X	
8.5000	0 +		2.8500	0 +	
9.0000	0 +		3.0000	0 +	
TOTAL	23 (.50000 = INTERVAL WIDTH)		TOTAL	23 (.15000 = INTERVAL WIDTH)	

FIGURE 34. Number of samples in stratum 4 that occur for each of the means and standard deviations. Means and standard deviations in phi units.

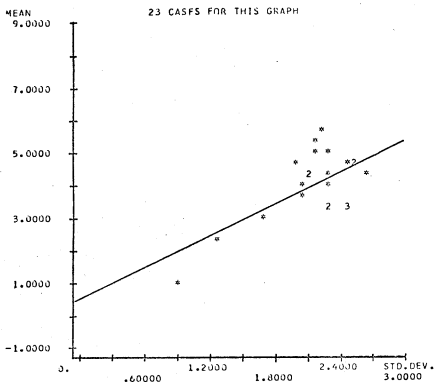


FIGURE 35. Plot of the means vs standard deviation of the means in phi units of samples in stratum 4.

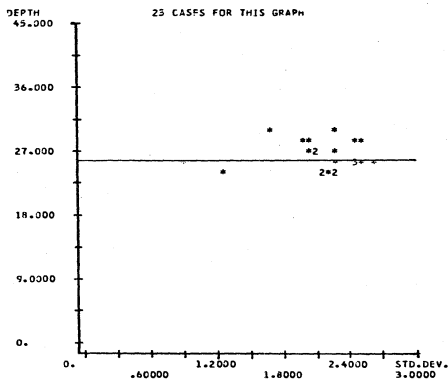
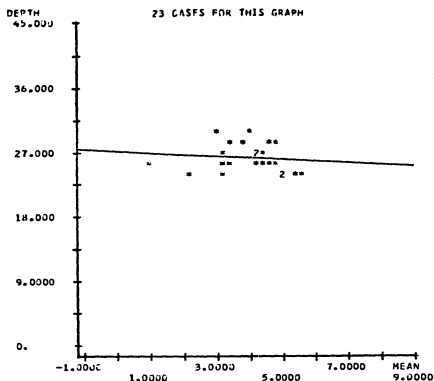


FIGURE 36. Plots of the means and standard deviations against depth (M) of samples in stratum 4.

HISTOGRAM/FREQUENCIES

STRATUM = 5

MIDPOINT	COUNT FOR MEAN	(EACH X =1)	MIDPOINT	COUNT FOR STD.DEV.	(EACH X =1)
-1.0000	0 +		0.	0 +	
-.50000	0 +		.15000	0 +	
0.	0 +		.30000	0 +	
.50000	0 +		.45000	0 +	
1.0000	0 +		.60000	1 +X	
1.5000	0 +		.75000	0 +	
2.0000	0 +		.90000	0 +	
2.5000	1 +X		1.0500	0 +	
3.0000	2 +XX		1.2000	0 +	
3.5000	1 +X		1.3500	0 +	
4.0000	0 +		1.5000	0 +	
4.5000	1 +X		1.6500	0 +	
5.0000	1 +X		1.8000	0 +	
5.5000	0 +		1.9500	0 +	
6.0000	0 +		2.1000	4 +XXXX	
6.5000	0 +		2.2500	1 +X	
7.0000	0 +		2.4000	0 +	
7.5000	0 +		2.5500	0 +	
8.0000	0 +		2.7000	0 +	
8.5000	0 +		2.8500	0 +	
9.0000	0 +		3.0000	0 +	
TOTAL	6 (.50000 = INTERVAL WIDTH)		TOTAL	6 (.15000 = INTERVAL WIDTH)	

FIGURE 37. Number of samples in stratum 5 that occur for each of the means and standard deviations. Means and standard deviations in phi units.

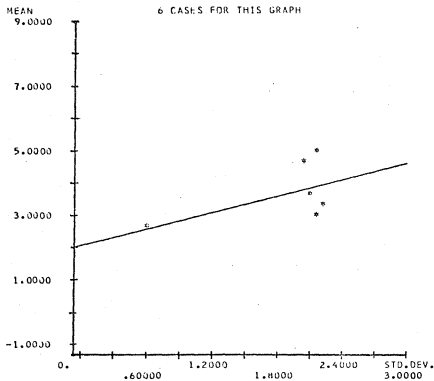


FIGURE 38. Plot of the means vs standard deviation of the means in phi units of samples in stratum 5.

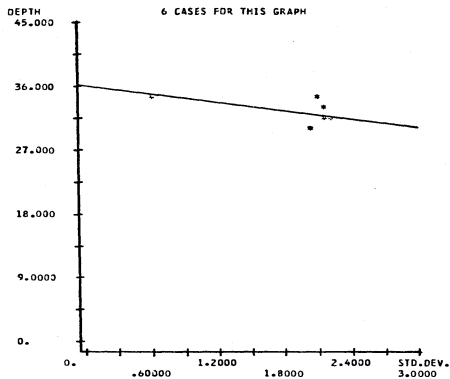
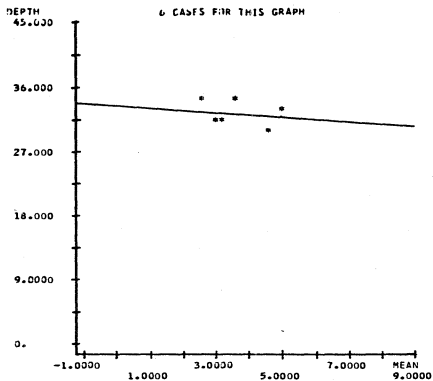


FIGURE 39. Plots of the means and standard deviations against depth (M) of samples in stratum 5.

Examination of the sample means and the standard deviation of the mean produces the general conclusion that the sediments in this portion of Lake Michigan can be divided into two sedimentation zones by the relationship of the means and depth and the standard deviation of the means with depth. The break in the two sedimentation zones occurs at about the 24-m depth contour. A transition zone between the two zones is present in the 18-24 m depth range, where the sediments show characteristics of both the deeper and shallower zones.

CONCLUSIONS

The character of the sediment in southeastern Lake Michigan in the vicinity of the Donald C. Cook Nuclear Power Plant proved to be much more diverse than previous studies had indicated. Sand is the dominant grain size material, with pockets of gravel and silt interspersed in the sand environment. The distribution of the sediments within this area of Lake Michigan can be attributed to the influence of the nearshore processes and the bottom topography. This was found to be particularly true within the closely spaced inner grid about the plant. The spacing of transects was found to influence the sediment distribution pattern. More closely spaced transects with the same station spacing along the transects showed a more anomalous distribution pattern than did more widely spaced transects. It is concluded that a closely spaced grid is essential to determine the distribution pattern within a small portion of the lake. Although in general there is a decrease in the mean grain size diameter with distance from shore and greater depths, this decrease is not a uniform one. Similar to the mean grain size diameter change, the sorting changes with depth and distance from shore. Again this change is not a uniform one and samples found in the same

depth and distance from shore showed marked differences in sorting, reinforcing the conclusion of patchiness of the sedimentation within this region of the lake.

The most important conclusion with regard to the sediment in the study area is that sedimentation appears to be occurring in two distinct depth regimes. The first depth regime is in water generally less than 24 m and the other is in depth greater than 24 m. The samples collected within the first depth zone generally were found to have mean grain size diameters of less than 3.0 phi units and a standard deviation of the mean of less than 1.8 phi units. The samples in the depth regime greater than 24 m had the mean greater than 3.0 phi and the standard deviation greater than 1.8 phi.

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COOK PLANT (INNER SURVEY) SURFICIAL SEDIMENT CHEMISTRY

Ronald Rossmann, Eric W. Olson and Donald A. Truman

Abstract. In the inshore region of the Cook Nuclear Plant, 66 surficial sediment stations were occupied. Results show that three sedimentary sinks are operative--carbonates, clay minerals, and iron compounds. Of these, the clay minerals appear to be the most important with respect to plant effluent uptake. As reflected by relatively high potassium concentrations, clay minerals are present near the intake-discharge of the plant, north of the plant, and south of the plant. These areas will require careful monitoring for possible concentration of plant effluents. The role of carbonates in effluent uptake is uncertain at the present time.

INTRODUCTION

With an increasing awareness of the deleterious environmental changes perpetrated by man, numerous individuals have expressed concern about the impact of nuclear power plants on the Great Lakes. The Cook Plant is one such generating station under construction. It is located on the southeastern shore of Lake Michigan (Fig. 1).

One anxiety is the fate of radioactive and non-radioactive chemical discharges to Lake Michigan. These discharges may behave in two ways. They may simply be diluted by lake water and add to the solute load of the lake, or they may be removed from solution by precipitation, biologic uptake, and/or adsorption processes. Any of these processes may result in concentration of an element. Those elements concentrated by biological processes will eventually be

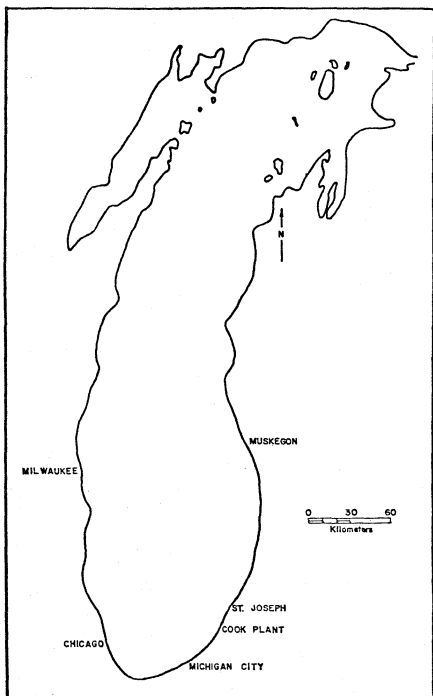


FIGURE 1. Location of the Donald C. Cook Nuclear Plant.

incorporated into the sediment when the organism dies. Elements adsorbed will suffer the fate of the particles adsorbing them. Possible materials found at the Cook Plant that are capable of adsorption are clay minerals, organic matter, carbonates, and ferromanganese oxides.

In order to predict the destiny of radioactive and stable element effluents released to Lake Michigan by the Cook Plant, to delineate areas where possible concentration of effluents may occur, to establish baseline data, and to discover and describe other near-site major sources of effluents, a comprehensive chemical study of the Cook Plant site has been undertaken. This study includes surficial sediments, lake water, interstitial water, and particulate matter analyses. Sampling and analysis of the last three will begin April 1974.

Surficial sediment analysis began with sample collection during September and October of 1973. The 158 stations occupied are divided into two groups. The general stations were sampled using a 1.6 km grid and the inshore stations (inner survey) using a modified 0.4 km grid. This report concerns the results of analyses of the 66 inshore stations (Fig. 2).

METHODS

Samples were collected using a Ponar grab sampler. Subsamples for chemical analysis, grain size analysis, and electrode measurements were removed from the top 2-3 cm of the grab samples. By inserting the electrodes and a thermometer directly into the sediment, field measurements of Eh, pH, and temperature were made on the samples immediately after collection. All pH measurements were made using a rugged pH electrode and a calomel fiber junction saturated potassium chloride reference electrode. Standardization for the measurements was accomplished using commercially available pH buffer solutions. Eh

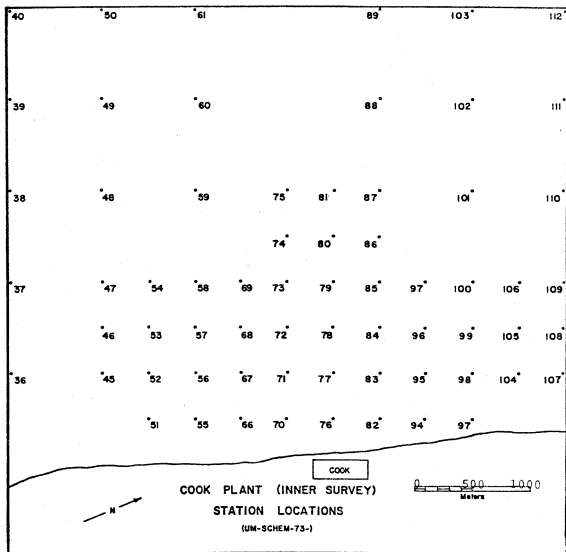


FIGURE 2. Location of inshore surficial sediment stations.

measurements made use of the same reference electrode and a platinum inlay electrode. Standardization was against Zobell's solution (Zobell 1946). Temperature measurements were made with a standard glass laboratory thermometer. After texture and color were noted, the sediment was stored in polyethylene bags for laboratory analysis.

In the laboratory, the samples were oven dried at 110°C and ground using a mixer mill. Two-gram ground samples for major, minor, and trace element analyses were extracted in a 10% hydrochloric acid-30% hydrogen peroxide solution kept hot (near boiling) for a period of 40 hr. The extract was separated from the insoluble residue by filtration through fritted glass funnels. The residue was then dried and weighed to obtain weight percent insoluble. The filtered extract was brought to volume in a 50 ml volumetric flask and stored in polyethylene bottles. Analyses for calcium, magnesium, sodium, potassium, manganese, iron, copper, cobalt, nickel, molybdenum, chromium, and zinc were done by standard atomic absorption spectrophotometry techniques (Perkin Elmer 1968). Barium, strontium, and total phosphorous analyses will be completed at a later date.

Total carbon analyses were done on oven dried (110°C) ground samples gasometrically by hydroxide absorption using a LECO carbon analyzer. Inorganic carbon was measured using a modification of the LECO carbon analyzer system whereby the sample is reacted with hot 2N hydrochloric acid (Kolpack and Bell 1968). Organic carbon is considered to be equal to total carbon minus inorganic carbon.

RESULTS

The area of study has a bottom topography which gently slopes offshore (Fig. 3). In general, the sediments are sands which progressively become more silty offshore. Chemical and physical data for each station are listed in Table 1. Table 2 lists average elemental concentrations and their ranges. The zinc value for station UM-SCHEM-73-51 is very high. This may be the result of either sample contamination or subsampling problems.

Areal distributions of each element are portrayed in Figures 4-18. In some instances, "bull's-eye" high concentration areas exist which are dependent upon one station. Elements with such highs are zinc, nickel, sodium, magnesium and calcium (lower left of figures) and nickel and copper (right and perhaps lower right of figures). Since these may or may not be representative, these highs should be viewed with caution.

The manganese distribution is particularly interesting. We believe manganese is concentrated in the surficial flocculent material, making its distribution particularly subject to local currents. The vast area of low manganese offshore of the plant site indicates a *possible* disturbance of the floc by pumping and/or construction activities. Later studies are needed to confirm or deny this observation.

DISCUSSION

Three major classes of sediment types are important to trace element distributions in the nearshore (less than 4200 m offshore) area of the Cook Plant--carbonates, clay minerals, and ferromanganese compounds. Carbonates include limestone and dolostone (Callender 1969). These are most strongly

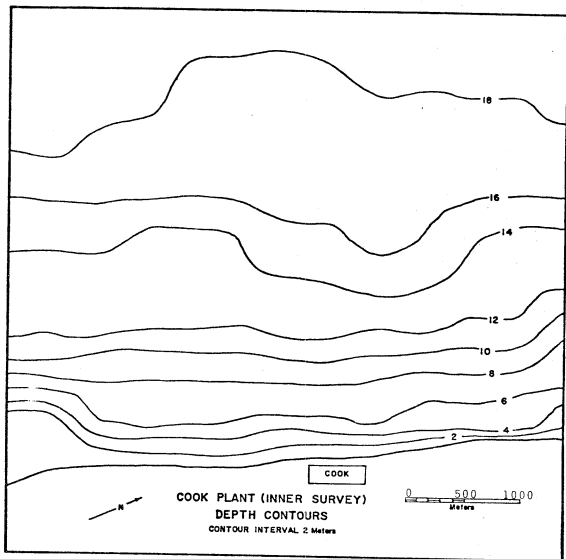


FIGURE 3. Bottom topography of the inshore region of the Cook Plant.

TABLE 1. Surficial sediment chemistry at the Cook Plant (Inner Survey). Units are weight percent of total sample except Eh, pH and depth. 0.0 indicates that an element was undetectable, and ** indicates when a parameter was not measured.

Station Number	Insoluble	Calcium	Magnesium	Iron	Manganese ($\times 10^{-3}$)	Sodium ($\times 10^{-2}$)	Potassium ($\times 10^{-4}$)	Cobalt ($\times 10^{-4}$)	Chromium ($\times 10^{-3}$)
UN-SCHEN-73-36	88.9	1.98	0.805	1.04	17.2	2.57	10.6	3.64	1.06
73-37	88.8	1.95	0.802	0.784	17.2	2.46	14.4	4.64	1.13
73-39	78.0	4.15	1.88	1.05	24.3	3.33	23.6	7.77	1.60
73-40	89.0	0.444	0.808	0.744	20.2	2.27	16.5	5.05	1.07
73-45	85.8	2.48	1.13	2.51	26.9	3.14	7.72	8.66	2.09
73-46	87.7	2.51	1.26	0.534	13.3	2.35	6.94	5.00	0.948
73-47	85.0	2.73	1.38	1.10	22.8	2.68	8.36	5.87	1.50
73-48	80.4	3.89	1.89	1.38	25.8	2.64	12.0	8.13	1.90
73-49	94.7	0.581	0.260	0.481	8.68	1.60	5.78	3.21	0.555
73-50	76.8	5.10	2.47	1.06	26.4	3.15	12.4	9.46	1.78
73-51	87.3	2.33	1.31	1.02	19.8	1.16	4.44	5.54	0.459
73-52	80.6	2.72	1.20	5.15	36.4	2.84	6.03	9.21	5.50
73-53	85.5	2.99	1.39	0.503	18.2	2.53	9.23	6.20	1.04
73-54	86.4	2.42	1.12	1.55	21.1	2.72	7.79	6.34	1.74
73-55	96.9	1.69	0.594	0.532	11.4	2.53	6.95	3.14	0.949
73-56	82.5	2.54	1.35	3.28	3.07	2.58	6.75	4.87	2.81
73-57	63.8	7.20	4.71	2.21	3.90	5.68	7.04	9.80	1.95
73-58	87.7	2.07	1.02	1.59	2.65	1.66	9.58	4.94	1.46
73-59	95.2	0.739	0.393	0.603	1.03	1.90	5.80	1.45	0.988
73-60	77.2	4.33	2.66	1.93	2.98	3.19	10.1	4.27	2.45
73-61	97.0	0.343	0.0113	0.448	11.7	1.32	9.87	3.83	0.321
73-66	87.3	2.69	1.36	0.597	1.30	2.48	7.29	2.39	1.06
73-67	86.7	2.31	1.00	2.80	2.63	2.29	6.96	3.64	2.44
73-68	87.1	2.07	1.18	1.79	1.93	2.70	7.36	4.29	1.61
73-69	87.4	2.39	1.29	1.37	2.05	2.28	7.68	3.55	1.52
73-70	89.6	2.12	0.923	0.668	1.08	2.75	7.99	3.65	0.878
73-71	87.7	2.46	1.21	0.883	1.45	2.85	8.22	3.07	1.24
73-72	91.6	1.51	0.705	0.768	0.957	2.24	8.35	3.76	1.13
73-73	93.2	1.30	0.602	0.667	0.733	2.17	5.83	2.50	1.04
73-74	93.6	1.04	0.550	0.721	1.14	2.12	5.79	3.02	1.04
73-75	90.7	1.66	1.01	0.907	1.22	2.16	6.78	3.69	1.02
73-76	**	1.34	0.439	0.480	0.785	2.32	7.61	2.48	0.656
73-77	87.0	2.56	1.17	1.33	1.85	3.02	8.05	3.72	1.41

TABLE 1 continued.

Station Number	Copper ($\times 10^{-4}$)	Molybdenum ($\times 10^{-4}$)	Nickel ($\times 10^{-4}$)	Zinc ($\times 10^{-4}$)	Total Carbon	Inorganic Carbon	Organic Carbon	Eh, mv	pH	Depth, m
UN-SCHEM-73-36	1.22	0.0	7.14	1.54	1.00	0.760	0.240	413	7.96	9.1
73-37	6.32	2.44	8.59	3.81	1.43	1.03	0.420	35	7.50	13.7
73-39	7.62	2.48	13.5	7.41	2.62	2.08	0.540	75	7.58	18.9
73-40	3.80	1.36	5.70	4.64	1.20	0.95	0.250	109	7.64	18.6
73-45	2.39	0.0	8.48	2.04	5.35	4.27	1.08	349	7.77	8.5
73-46	2.67	3.88	7.32	2.36	0.870	0.950	0.0	381	7.66	13.1
73-47	3.85	0.0	8.83	2.97	1.39	1.00	0.390	208	7.51	13.7
73-48	5.57	6.93	10.9	4.82	2.02	1.74	0.28	122	7.69	17.1
73-49	1.51	0.0	3.40	1.89	2.45	0.080	2.37	391	7.62	18.6
73-50	6.87	7.82	12.3	5.57	2.67	2.37	0.300	97	7.54	18.9
73-51	1.61	3.85	6.90	22.3	0.570	0.060	0.510	**	**	7.0
73-52	2.98	0.0	9.87	2.67	1.21	1.08	0.130	432	7.81	8.2
73-53	4.25	4.85	8.94	3.09	1.57	1.39	0.180	362	7.40	12.2
73-54	3.61	0.0	8.54	2.79	0.890	1.04	0.0	429	7.63	13.4
73-55	1.74	0.0	5.33	1.16	0.670	0.480	0.190	338	7.81	6.7
73-56	2.96	1.48	9.55	2.19	1.15	1.02	0.130	421	7.92	8.5
73-57	4.54	5.49	20.4	4.18	2.00	1.65	0.35	**	**	12.5
73-58	4.03	1.46	10.7	2.66	0.990	1.14	0.0	363	7.67	13.4
73-59	1.73	0.0	5.76	1.57	0.310	0.100	0.210	443	7.60	16.4
73-60	4.40	4.56	12.6	4.27	2.07	2.04	0.030	382	7.70	17.7
73-61	1.23	0.0	4.17	2.96	0.330	0.130	0.200	436	7.70	18.9
73-66	2.39	0.10	7.76	1.88	1.18	0.840	0.340	402	7.73	6.1
73-67	2.43	0.0	8.21	1.91	0.880	0.480	0.400	399	7.85	8.5
73-68	2.59	0.0	7.50	2.73	0.950	0.670	0.280	369	7.81	11.9
73-69	3.04	0.0	6.20	2.16	1.02	0.670	0.350	380	7.64	13.7
73-70	2.43	0.0	6.90	1.38	0.990	0.310	0.680	419	7.93	5.8
73-71	2.72	1.57	6.99	1.59	1.13	0.890	0.240	378	7.60	8.8
73-72	3.90	0.0	8.29	2.21	1.05	0.420	0.630	**	**	12.8
73-73	1.51	1.60	4.83	1.30	0.580	0.530	0.050	408	7.78	14.0
73-74	1.70	0.0	5.09	2.14	0.300	0.380	0.0	378	7.64	15.5
73-75	2.66	0.71	6.14	2.59	0.700	0.370	0.330	189	7.76	17.1
73-76	1.46	0.0	5.44	1.62	0.580	0.400	0.180	412	7.97	5.8
73-77	2.46	1.38	7.90	3.11	1.040	0.820	0.220	336	7.79	9.1

TABLE 1 continued.

Station Number	Insoluble	Calcium	Magnesium	Iron	Manganese ($\times 10^{-3}$)	Sodium ($\times 10^{-2}$)	Potassium ($\times 10^{-2}$)	Cobalt ($\times 10^{-4}$)	Chromium ($\times 10^{-3}$)
UN-SCHEN-73-78	82.8	3.14	1.46	1.24	2.29	2.36	17.6	5.44	2.31
73-79	87.3	2.20	1.13	1.69	21.3	2.84	8.05	4.14	1.94
73-80	95.3	0.665	0.356	0.819	15.5	1.86	5.26	3.75	0.935
73-81	89.8	1.75	0.966	1.13	18.2	2.65	7.16	3.49	1.54
73-82	88.2	2.29	0.736	1.56	26.4	2.49	8.58	5.65	1.38
73-83	89.2	2.27	0.973	0.635	13.4	2.14	6.81	2.76	1.11
73-84	84.7	3.18	1.51	0.751	19.6	3.25	10.2	4.45	1.40
73-85	85.1	2.92	1.35	1.17	21.6	2.78	10.2	4.27	1.91
73-86	84.01	3.17	1.62	0.947	19.2	3.26	8.66	4.87	1.40
73-86B	77.9	4.41	1.94	1.45	25.6	3.06	21.0	6.34	3.15
73-87	96.6	0.518	0.170	0.293	8.07	1.67	5.66	3.04	0.707
73-88	79.1	4.30	2.12	1.36	26.6	3.23	12.2	5.56	2.30
73-89	97.8	0.273	0.0	0.156	5.78	1.37	7.10	2.37	2.85
73-90	93.0	1.56	0.549	0.858	11.9	2.72	6.51	2.14	1.37
73-90A	91.8	1.55	0.438	0.603	13.1	2.30	6.72	3.30	1.04
73-95	91.4	1.84	0.739	0.455	12.0	2.72	8.88	3.41	1.08
73-96	79.6	4.34	1.88	1.07	24.0	2.85	16.0	5.39	2.30
73-97	88.4	2.29	1.12	0.715	15.1	2.54	7.74	3.15	1.17
73-98	91.8	1.81	0.781	0.277	12.2	1.75	6.19	1.95	0.930
73-99	95.2	0.952	0.422	0.193	7.94	2.88	6.79	2.31	0.519
73-100	96.8	0.560	0.249	0.141	6.20	1.67	5.50	1.98	0.530
73-101	96.1	0.680	0.369	0.270	7.76	1.47	5.24	2.14	0.746
73-102	97.6	0.325	0.852	0.349	7.26	1.03	3.70	2.37	0.663
73-103	94.8	0.894	0.479	0.369	11.0	1.49	7.19	2.90	0.947
73-104	92.6	1.77	0.672	0.230	9.26	2.33	8.16	3.32	0.710
73-105	93.7	1.31	0.478	0.546	10.7	1.94	6.48	3.37	1.02
73-106	97.7	0.374	0.135	0.252	7.59	1.36	4.69	2.65	0.511
73-107	92.6	1.04	0.218	1.54	26.8	2.56	10.7	5.79	0.700
73-108	89.9	1.82	0.594	1.32	15.1	2.70	11.4	4.36	1.22
73-109	89.1	2.04	0.609	1.18	16.5	2.39	12.3	6.19	1.14
73-110	80.4	2.54	1.69	1.09	21.8	3.15	24.8	9.11	1.98
73-111	93.3	1.16	0.836	0.427	9.99	2.35	10.1	3.51	0.796
73-112	97.2	0.385	0.193	0.287	4.82	1.72	9.54	2.50	0.570

TABLE 1 continued.

Station Number	Copper ($\times 10^{-4}$)	Molybdenum ($\times 10^{-4}$)	Nickel ($\times 10^{-4}$)	Zinc ($\times 10^{-3}$)	Total Carbon	Inorganic Carbon	Organic Carbon	Eh, mv	pH	Depth, m
UK-SCHEN-73-78	13.4	2.48	14.4	6.50	2.14	1.35	0.790	60	7.17	13.1
73-79	3.27	0.72	6.92	2.84	1.06	0.690	0.370	371	7.88	14.0
73-80	1.66	1.57	6.24	2.48	0.350	0.090	0.260	**	**	15.8
73-81	2.32	1.36	6.38	3.41	0.520	0.840	0.0	377	7.70	16.4
73-82	3.34	1.57	11.0	3.12	0.890	0.400	0.490	**	**	6.4
73-83	2.22	0.71	5.46	2.17	0.960	0.830	0.130	383	7.81	8.2
73-84	3.83	2.46	8.26	3.56	1.52	1.21	0.310	440	7.69	11.9
73-85	5.13	2.43	8.94	3.92	1.51	1.28	0.32	230	7.87	14.6
73-86	2.88	3.36	8.43	3.67	1.58	1.19	0.30	420	7.57	16.8
73-86B	16.0	4.19	17.6	7.87	2.62	1.95	0.67	45	7.42	16.8
73-87	1.03	0.0	3.19	2.51	0.20	0.13	0.07	150	7.76	16.8
73-88	5.50	2.45	11.9	5.37	2.16	1.83	0.33	107	7.39	18.0
73-89	0.28	0.0	2.42	1.92	0.27	0.14	0.13	410	7.62	19.2
73-94	1.24	0.0	4.38	1.66	0.85	0.39	0.46	413	7.87	4.9
73-94A	1.57	0.0	5.96	3.68	0.73	0.47	0.26	**	**	4.9
73-95	1.62	2.21	5.29	3.60	0.95	1.01	0.0	361	7.86	7.9
73-96	9.59	2.99	12.2	4.98	2.20	1.89	0.31	80	7.46	12.2
73-97	2.74	2.22	6.71	2.96	1.27	1.14	0.13	354	7.85	14.3
73-98	1.31	1.33	5.00	2.07	1.05	0.80	0.25	405	7.89	7.3
73-99	1.51	0.0	3.99	2.29	0.72	0.60	0.12	480	7.76	11.3
73-100	0.91	0.0	3.13	1.88	0.48	0.39	0.09	461	7.89	13.4
73-101	1.13	0.0	3.56	2.46	0.82	0.55	0.27	403	7.68	16.4
73-102	0.83	0.0	3.32	2.01	0.24	0.03	0.21	479	7.62	18.0
73-103	2.55	0.0	5.21	3.73	0.92	0.72	0.20	419	7.42	19.8
73-104	1.74	0.0	5.54	2.65	1.05	0.86	0.19	320	7.64	7.6
73-105	1.60	0.0	4.17	2.27	0.97	0.68	0.29	369	7.69	11.9
73-106	1.14	0.0	3.46	1.73	0.19	0.04	0.15	398	8.11	12.8
73-107	1.10	4.38	7.07	2.23	0.78	0.37	0.41	**	**	6.7
73-108	1.07	7.12	6.59	2.86	1.00	0.92	0.08	456	7.83	8.2
73-109	1.90	5.31	10.2	3.17	0.52	0.40	0.12	446	7.47	12.2
73-110	10.6	0.87	13.9	6.07	2.31	1.80	0.51	87	7.66	16.2
73-111	1.48	0.0	5.38	3.55	1.17	0.54	0.63	379	7.73	18.3
73-112	0.32	0.0	2.99	2.42	0.58	0.58	0.0	439	7.67	19.5

TABLE 2. Average elemental concentrations for Cook Plant (Inner Survey) surficial sediments.

Element	Mean ¹	Standard Deviation ¹	Range ¹
Ca	2.09	1.19	0.273 - 7.20
Mg	1.01	0.59	0.0 (tr.) - 4.71
Fe	1.02	0.85	0.141 - 5.15
Mn	0.0124	0.0089	0.000733 - 0.0364
Na	0.0241	0.0058	0.0103 - 0.0568
K	0.0928	0.0435	0.0370 - 0.248
Co	0.000437	0.000199	0.000145 - 0.000980
Cr	0.00134	0.000805	0.000285 - 0.00550
Cu	0.000320	0.000287	0.00032 - 0.00160
Mo	0.000153	0.000199	0.0 ² - 0.000782
Ni	0.000758	0.000352	0.000242 - 0.00204
Zn	0.00306	0.00148	0.00116 - 0.00787
Total Carbon	1.22	0.85	0.19 - 5.35
Inorganic Carbon	0.94	0.72	0.03 - 4.27
Organic Carbon	0.31	0.37	0.0 - 2.37

¹Weight percent of total sample.

²0.0 = means undetectable.

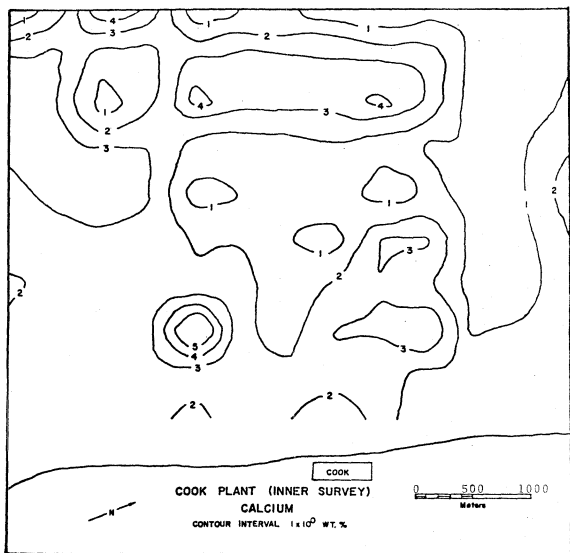


FIGURE 4. Areal distribution of calcium in the inshore region of the Cook Plant.

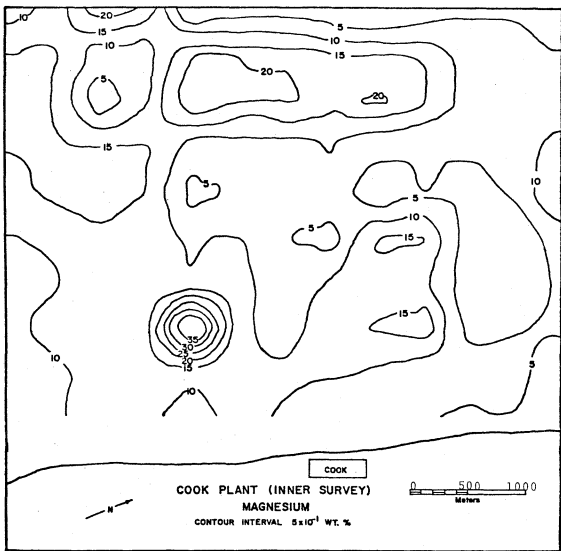


FIGURE 5. Areal distribution of magnesium in the inshore region of the Cook Plant.

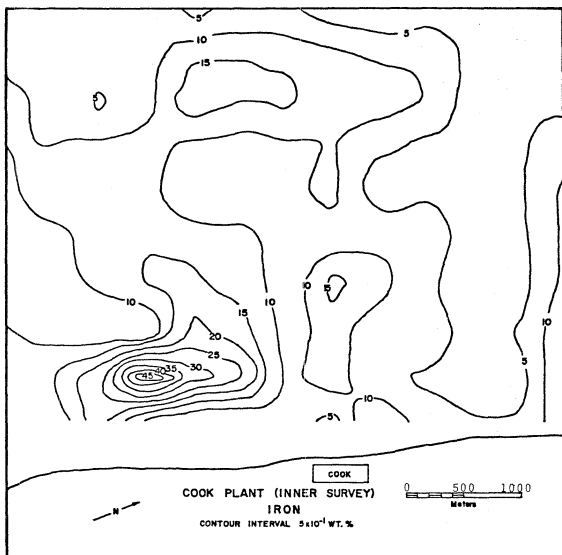


FIGURE 6. Areal distribution of iron in the inshore region of the Cook Plant.

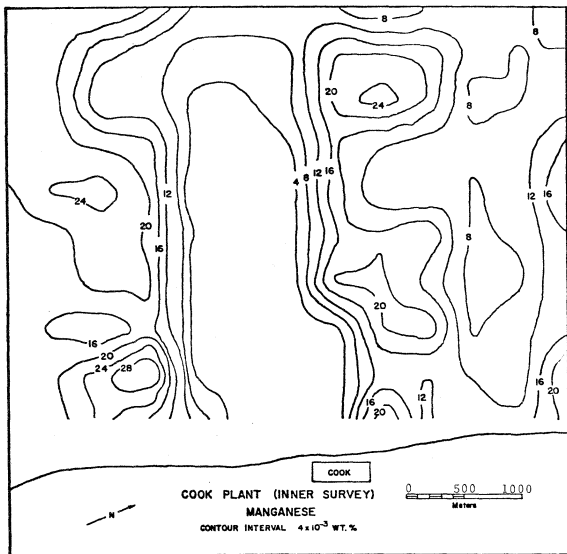


FIGURE 7. Areal distribution of manganese in the inshore region of the Cook Plant.

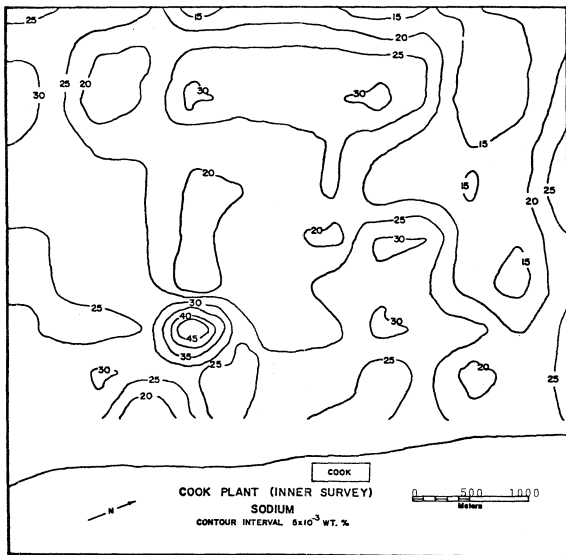


FIGURE 8. Areal distribution of sodium in the inshore region of the Cook Plant.

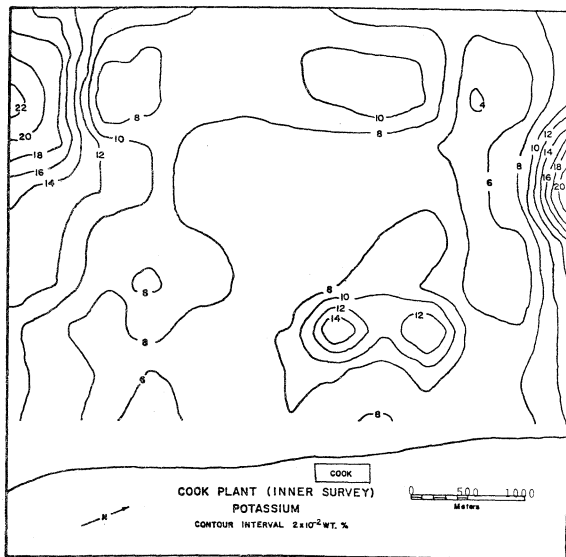


FIGURE 9. Areal distribution of potassium in the inshore region of the Cook Plant.

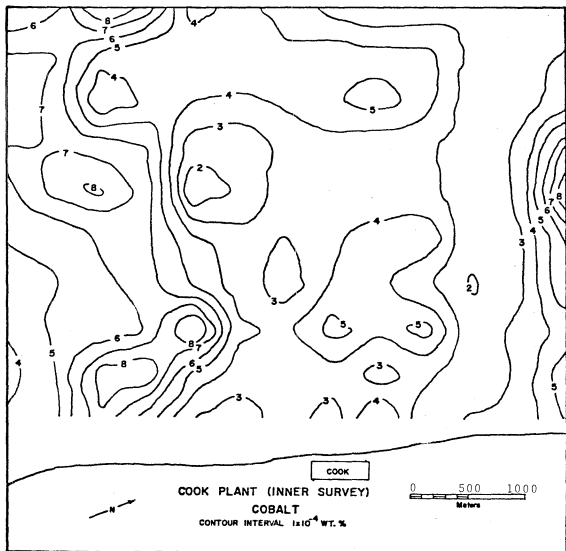


FIGURE 10. Areal distribution of cobalt in the inshore region of the Cook Plant.

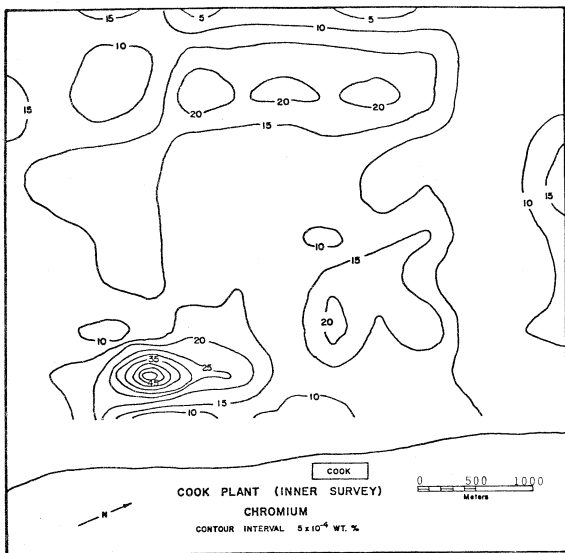


FIGURE 11. Areal distribution of chromium in the inshore region of the Cook Plant.

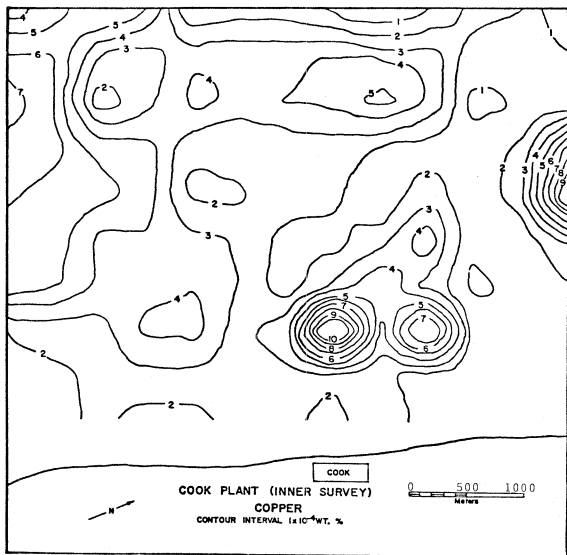


FIGURE 12. Areal distribution of copper in the inshore region of the Cook Plant.

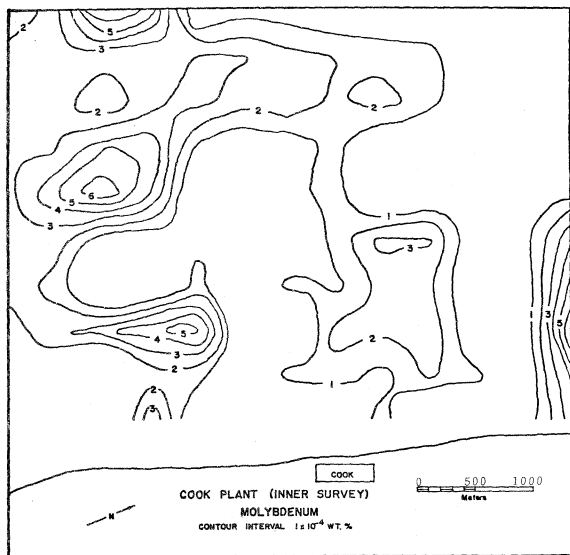


FIGURE 13. Areal distribution of molybdenum in the inshore region of the Cook Plant.

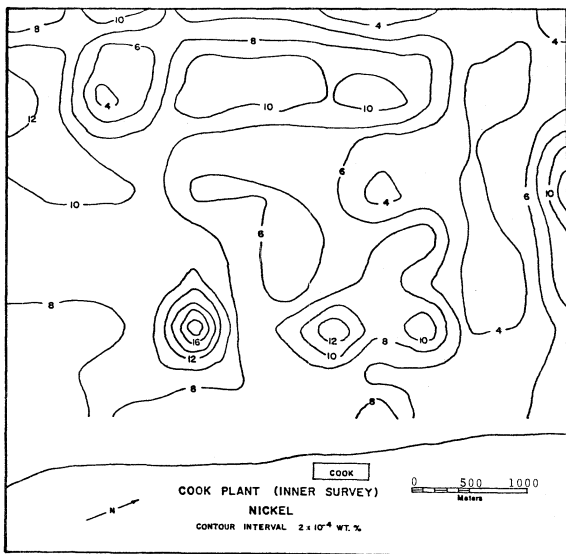


FIGURE 14. Areal distribution of nickel in the inshore region of the Cook Plant.

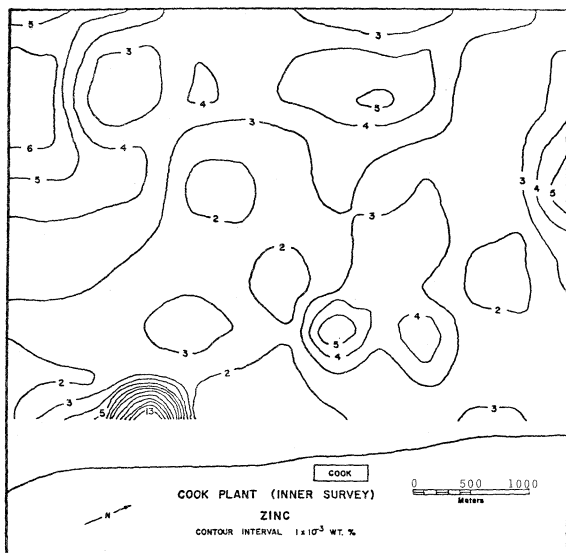


FIGURE 15. Areal distribution of zinc in the inshore region of the Cook Plant.

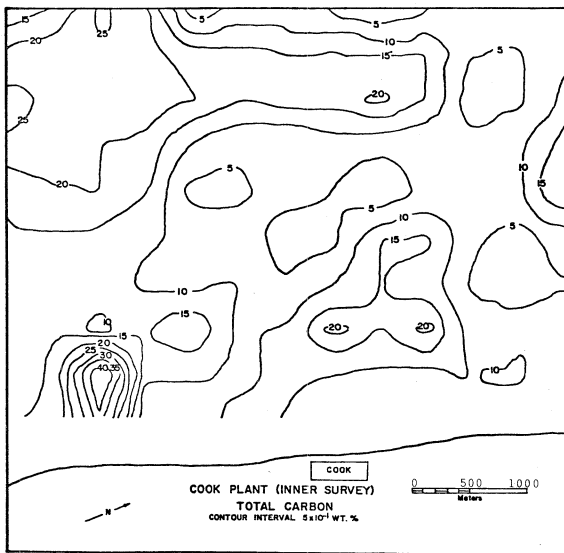


FIGURE 16. Areal distribution of total carbon in the inshore region of the Cook Plant.

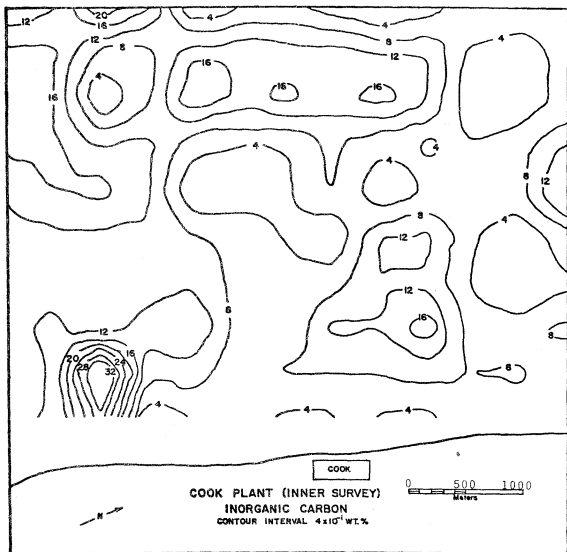


FIGURE 17. Areal distribution of inorganic carbon in the inshore region of the Cook Plant.

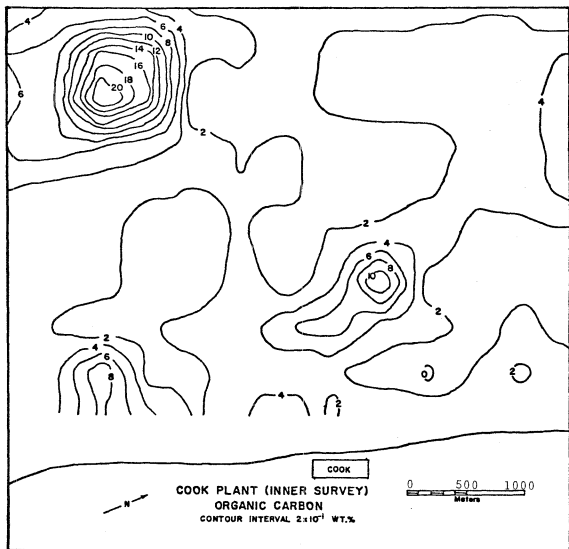


FIGURE 18. Areal distribution of organic carbon in the inshore region of the Cook Plant.

associated with areas of relatively high silt concentration. Since the silt concentration contours align with the depth contours and highest silt concentrations appear in areas with a relatively low angle of slope, the carbonates are believed detrital. They are most likely derived from the bluffs along-shore and redistributed by local water currents. Being detrital and chemically unreactive in the inshore environment, they most likely will have little effect on plant effluents. However, laboratory studies are required to determine possible uptake reactions. This carbonate sink is outlined by areas having high calcium, magnesium, and inorganic carbon concentrations.

Clay minerals which are present in Lake Michigan sediments are chlorite, "illite," mixed layer, kaolinite, and montmorillonite (C. J. Bowser and K. A. Johansen, personal communications). These clay minerals generally have a negative surface charge and undergo ion exchange reactions (Carroll 1959). Because of their negative charge, cations are removed from solution. This process is continually taking place. Unlike the detrital carbonates, the clays are capable of removing trace elements from solution discharged by the plant. One ion other than calcium and magnesium which takes place in cation exchange reactions is potassium (Carroll 1959). Hence, potassium is a good indicator of the clay mineral sedimentary sink.

Ferromanganese compounds found in Lake Michigan include various X-ray amorphous materials, goethite, psilomelane, birnessite, todorokite, and rhodochrosite (Rossmann 1973). Since manganese compounds are nearly non-existent in the inshore area, only goethite and X-ray amorphous hydrated ferric hydroxides are of major importance. These materials are known to adsorb anions (Rossmann, Callender and Bowser 1972). The logical indicator for this sink is iron.

Within the boundaries of the survey, various elements behave in a similar manner. In order to become aware of all of these relationships, a correlation coefficient matrix was calculated (perfect correlation ± 1.0). Table 3 lists the matrix. Those variables which do not exhibit a strong direct or inverse relationship with any of the other variables are organic carbon, pH, and depth. From this matrix and factor analysis, the elements associated with the carbonate sink are calcium, magnesium, sodium, cobalt, chromium, nickel, zinc, total carbon, and inorganic carbon; with the clay minerals are potassium, cobalt, copper, nickel, and zinc; and with iron compounds are iron and chromium. Though cobalt is associated with manganese, the manganese sink is relatively inoperative and of little importance in the inshore region. The reason for this is manganese compounds and clay minerals are both competing for the same cations. Though manganese oxides are stronger adsorbers of cations, they have little control on the distribution of cations. Manganese oxides are not abundant and thus cannot compete with the more abundant clay minerals for the bulk of cations available for uptake.

CONCLUSION AND RECOMMENDATIONS

Clay minerals appear to be the most important active reservoir for the uptake of trace materials in the inshore region of the Cook Plant. This may or may not be true for offshore areas. Materials released by the plant will most likely concentrate in inshore areas of high clay mineral content (areas of high potassium). However, the role of carbonates with respect to trace element adsorption is unknown for this area. Laboratory studies will be required to assess the relative importance of the carbonates and clay minerals. Because of possible physical disruption of surficial sediments both past and

TABLE 3. Correlation matrix for surficial sediment data.

Variable	Cu	Hg	Fe	Mn	Na	K	Co	Cr	Cu	Mo	Ni	Zn	Total Carbon	Inorganic Carbon	Organic Carbon	Insoluble Residue	Eh	pH	Depth
Cu	1.00	0.94	0.42	0.49	0.79	0.52	0.66	0.62	0.68	0.58	0.87	0.63	0.63	0.72	0.08	-0.81	-0.51	-0.29	-0.08
Hg		1.00	0.42	0.42	0.74	0.51	0.65	0.61	0.67	0.52	0.85	0.64	0.61	0.71	0.06	-0.80	-0.51	-0.29	0.06
Fe			1.00	0.32	0.43	0.08	0.56	0.90	0.22	0.12	0.49	0.12	0.33	0.38	0.03	-0.60	-0.04	0.11	-0.24
Mn				1.00	0.48	0.44	0.72	0.50	0.39	0.43	0.46	0.52	0.52	0.58	0.13	-0.55	-0.41	-0.18	0.12
Na					1.00	0.48	0.58	0.55	0.46	0.37	0.67	0.46	0.57	0.65	0.08	-0.74	-0.34	-0.05	-0.24
K						1.00	0.60	0.29	0.81	0.42	0.75	0.86	0.50	0.51	0.17	-0.49	-0.73	-0.44	0.26
Co							1.00	0.63	0.59	0.48	0.75	0.62	0.68	0.73	0.15	-0.80	-0.53	-0.30	0.12
Cr								1.00	0.52	0.26	0.68	0.41	0.43	0.50	0.07	-0.68	-0.29	-0.08	-0.15
Cu									1.00	0.40	0.87	0.85	0.56	0.55	0.24	-0.58	-0.77	-0.53	0.19
Mo										1.00	0.53	0.52	0.29	0.38	-0.04	-0.37	-0.32	-0.28	0.15
Ni											1.00	0.78	0.62	0.69	0.13	-0.79	-0.62	-0.42	0.06
Zn												1.00	0.52	0.56	0.14	-0.53	-0.77	-0.54	0.43
Total Carbon													1.00	0.91	0.54	-0.87	-0.48	-0.27	0.04
Inorganic Carbon														1.00	0.17	-0.92	-0.47	-0.25	0.01
Organic Carbon															1.00	-0.23	-0.22	-0.09	0.09
Insoluble Residue																1.00	0.45	0.20	0.07
Eh																	1.00	0.45	-0.31
pH																		1.00	-0.47
Depth																			1.00

future (evidenced by the manganese areal distribution), we recommend that another inner survey be made after continuous pumping has commenced. At this time, we recommend that the areas of high potassium (clay minerals) be monitored most closely for both radioactive and non-radioactive materials released by the plant. Further data may require rejection of this current recommendation.

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UNDERWATER OPERATIONS IN SOUTHEASTERN LAKE MICHIGAN
NEAR THE DONALD C. COOK POWER PLANT DURING 1973

John A. Dorr III

Abstract. Underwater operations in the vicinity of the Donald C. Cook Nuclear Plant were started in 1973. These underwater surveys produced results that have prompted the continuation of this visual observation program, since they permit a correlation to be made between mechanical sampling of the area and actual man collected and man inspected samples. The program to be undertaken in 1974 is summarized and the areas of concentration of visual observations are given.

INTRODUCTION

Underwater operations were conducted in the vicinity of the Donald C. Cook Nuclear Plant during three months in 1973. A total of eleven dives to collect scientific data were made on June 17-18, August 10, 15-16, and September 21.

Open circuit SCUBA was used for all dives, with a 16-foot Boston Whaler functioning as the support vessel. Inclement weather and limited visibility hampered the diving operations. Underwater times ranged from 15 to 71 minutes per dive. The data obtained were either written on underwater tablets or committed to memory and transcribed on the surface. Underwater operations serve the primary function of providing visual observations made by members of the research team, of areas usually sampled by mechanical means. The program of observations in this formative period was conducted on an informal basis, with one or two organized experiments included. The organized experiments proved that visual observations are useful, and a more detailed

underwater survey operation is being conducted in 1974 as outlined in the summary of this paper.

RESULTS AND DISCUSSION

The 1973 season marked the inception of the underwater survey program and, as noted, problems of weather, equipment and timing resulted in relatively few dives. However, the program produced substantive results, and these results are summarized as follows:

Date	17 June	Dive No. 1
Location	South discharge structure	
Depth	18-22 ft.	
Team	John Dorr, Tim Miller, Susan Williams, Tom Bottrell	
Time	1403-1430 hrs. (27 min.)	

Observations

Horizontal visibility at working depth was 2-3 ft. Temperature was a constant 18°C. Slight current from the south.

Heavy accumulations of tree limbs and roots, pipe and other steel scrap were covering the bottom adjacent to the north and west sides of the structure. Debris accumulation was lighter on the east and south sides. Bottom consisted of 6-12 inch riprap.

Random clumps of 1-inch high *Cladophora* were growing on the top of the structure. A light periphyton growth covered the structure and the surrounding riprap.

Two 6-inch yellow perch and 10-15 johnny darters were observed.

No rooted macrophytes were observed.

* * * * *

Date	17 June 1973	Dive No. 2
Location	South intake crib	
Depth	15-30 ft	
Team	John Dorr, Tim Miller, Tom Bottrell, Susan Williams	
Time	1505-1540 hrs. (35 min.)	

Observations

Horizontal visibility at working depth was 6-8 ft. Temperature was a constant 18°C. Slight current from the south.

The bottom was composed of 6-12 inch riprap, lightly covered with silt. No large accumulations of debris were observed.

All surfaces of the crib structure supported periphyton growth. Growth was most luxuriant on the more protected areas of the structure. The top of the structure was covered by a mat of *Cladophora* 1/2 - 1-1/2 inches high, samples of which were collected and later examined in the laboratory. Some silt was mixed into the *Cladophora*.

Nine yellow perch (10-13 inch size class) were seen swimming randomly about the structure. Ten adult sculpins and 10-15 johnny darters were observed in the riprap.

* * * * *

Date	17 June 1973	Dive No. 3
Location	South intake crib	
Depth	15-30 ft.	
Team	John Dorr, Susan Williams, Tom Bottrell	
Time	2114-2225 hrs. (71 min.)	

Observations

Horizontal visibility at working depth (with underwater lights) was 4-6 ft. Temperature was a constant 18.5°C. Current was estimated at 0.5 knots from the south.

Dive time was divided equally between the base and the top of the crib. At the base of the structure 60-75 six-to-ten inch and 15-20 ten-to-fourteen inch yellow perch were observed swimming randomly and resting in a head down position in the riprap. Trout-perch, sculpins, johnny darters and several crayfish were also seen on the riprap.

Divers were on top of the crib approximately 30 minutes, and during that period saw 500-1000 spottail shiners swimming above and into the patches of 1-1/2 inch high *Cladophora*. Many of these fish appeared to be swollen (gravid), and when captured and squeezed they exuded eggs and milt. Several females were observed to deposit eggs into the *Cladophora*, but subsequent fertilization by males was not observed. Earlier during this dive, several yellow perch resting on the riprap were captured and squeezed, and they too exuded eggs and milt.

Samples of the *Cladophora* were collected, examined in the laboratory, and found to contain fish eggs of two distinct size (diameter) classes. When the diameters of eggs taken earlier that month from ripe spottails and perch were compared with these latest samples, the two size classes correlated closely. Alewife eggs (too small), sculpin and trout-perch eggs (too large) were ruled out as possibilities of being the species of eggs found in the *Cladophora*. Considering the

close size correlation, relative abundance of fish species, spawning times and the egg sizes of other species found in the area, it was concluded that the eggs found in the *Cladophora* had been deposited there by spottail shiners and yellow perch.

A total of five different species of fish were seen on this dive. The variety of species observed and the level of their activity during this period of nighttime observation was much higher than any period of daytime observation. Observations of fish may be summarized as follows:

<u>Species</u>	<u>No. observed</u>	<u>Location</u>	<u>Behavior</u>
Spottail shiner	20-30 adults 500-1000	bottom 7 ft top of structure	random swimming schooling, spawning?
Alewife	200	throughout water column	swimming randomly
Yellow perch	60-75 (6-10") 15-20 (10-14")	bottom 7 ft of water	resting on riprap swimming randomly
Trout-perch	40-60	same as perch	same as perch
Sculpin	3-5	between riprap	not swimming, solitary

* * * * *

Date	18 June 1973	Dive No. 4
Location	Lake Michigan off Warren Dunes State Park	
Depth	25-35 ft.	
Team	John Dorr, Tom Bottrell	
Time	1817-1916 hrs. (59 min.)	

Observations

Horizontal visibility at working depth was 6-8 ft. Temperature was a constant 18°C. Current from south estimated to be less than 0.5 knot.

The dive consisted of rectangular transect swim with the rectangle oriented lengthwise in a north-south direction. The shore side of the transect was swum at the 25-ft. contour (water depth), and the lake side swum at the 35-ft. contour.

The bottom consisted of well sorted sand overlain with a fine layer of silt. One-inch high ripple marks were running from the southwest. No rooted macrophytes or debris of any sort were observed.

Ten live and one dead alewife were counted during the dive. Ten fingernail clam shells (*Sphaeriidae*) were counted.

In general, the area surveyed on this dive was the most "biologically barren" of any observed. The bottom was quite uniform and diversity of observed fauna very low.

* * * * *

Date	10 August 1973	Dive No. 5
Location	South intake crib	
Depth	15-35 ft.	
Team	John Dorr, Tim Miller, Bruce Higgins	
Time	1128-1202 hrs. (34 min.)	

Horizontal visibility at working depth was 15 ft. This was the highest visibility encountered on any dive. Temperature was a constant 21°C. No noticeable current.

The bottom surrounding crib consisted of 6-12 inch riprap, covered with a light accumulation of silt. Patchy accumulations of organic debris were observed on both riprap and sandy areas of the bottom. No rooted macrophytes were observed.

The top of the crib was covered with *Cladophora* 1-1/2 inches high, coated with a thin layer of silt. Periphyton grew in varying densities on all examined surfaces of the crib.

For the first time, a population of the aquatic snail (*Physa integra*) was noted to be inhabiting the riprap. A rough estimate of the density of organisms was 3-5 snails per m². Size of the snails ranged from 0.5-1.0 cm. A few crayfish were seen in the riprap.

Several schools of alewife fry (1 - 1-1/2 inch size class) were observed on the side east of the crib. Johnny darters and sculpins were noted in the riprap.

The crib and surrounding riprap area had evidently remained undisturbed for several weeks prior to this dive, which might explain the increase in fauna observed compared to previous dives in the area.

* * * * *

Date	15 August 1973	Dive No. 6
Location	South intake crib	
Depth	15-35 ft.	
Team	John Dorr, Susan Williams, Bruce Higgins	
Time	1723-1803 hrs. (40 min.)	

Observations

Horizontal visibility at working depth was 4 ft. Surface water temperature 21°C, bottom temperature 11°C. Current was from the south at approximately 1 knot.

A sharp thermal interface was encountered at 15 ft. which had not been present on previous dives. The interface was probably created by settling conditions, following a storm (and accompanying upwelling) which occurred several days prior to the dive.

Cladophora growth on the structure was patchy and more luxuriant at the top edges of the crib than in the center of the crib top. Samples of *Cladophora* were found to be covered with periphyton, predominately *Cymbella* sp., *Gomphonema* sp. and *Cocconeis* sp. There was an unusually heavy layer of silt on top of the crib, probably a result of the recent storm turbulence. The silt consisted primarily of dead diatoms.

No fish were observed. The riprap surrounding the base of the crib was not examined due to low visibility.

* * * * *

Date	16 August 1973	Dive No. 7
Location	South Discharge structure	
Depth	20-30 ft.	
Team	John Dorr, Susan Williams, Bruce Higgins	
Time	1103-1213 hrs. (70 min.)	

Observations

Horizontal visibility at working depth was 6-7 ft. Water temperature was 21°C, with occasional pockets of 18°C water near the bottom. No noticeable current.

Riprap size ranged from 3-36 inches in diameter. Evidence indicated that dumping, dredging or other disruptive operations had recently taken place in the area.

A few sculpins and 4 johnny darters were seen in the riprap. Several rhizomes from dune grass debris were collected, and upon later examination snail and chironomid eggs were found attached to some of them.

Both this structure and the intake structure examined on the previous day were quite "biologically barren."* This condition was probably the result of heavy construction operations which had recently been taking place in both areas, resulting in heavy silting and habitat disturbance.

* * * * *

Date	21 September 1973	Dive No. 8
Location	South intake crib	
Depth	14-30 ft.	
Team	John Dorr, Susan Williams	
Time	1055-1205 hrs. (70 min.)	

* "biologically barren" is defined here as a distinct lack of observable macroscopic flora or fauna.

Observations

Horizontal visibility at working depth was 4 ft. Temperature was a constant 13.5°C. No noticeable current.

The bottom surrounding the structure was composed of 3-8 inch riprap. North of the structure the riprap was silty and covered with *Cladophora* 1-1/2 inches high. This covering would indicate that the bottom in this area had remained undisturbed for a period of time.

An effort was made to determine the density of snails (*Physa integra*) and sculpins on the riprap surrounding the intake structure. One transect 1 m wide and 9 m long was swum at each of three compass points (N,E,S). The transects began at the base of the crib and proceeded outward perpendicular to it. A count was taken of the number of snails and sculpins observed, and later a density index was calculated.

Transect (compass point)	N	S	E
Area of transect (m ²)	9	9	9
Snail count	23	0	3
Snail density (No./m ²)	2.5	0	0.3
Sculpin count	5	0	1
Sculpin density (No./m ²)	0.6	0	0.1
Bottom type	silty riprap	clean sand	clean riprap

Snails and sculpins were observed in numbers only in the area (north transect) where the riprap appeared to have remained undisturbed for a period of time. Sandy or clean riprap areas were quite barren. Snail size averaged 3-5 mm with a few specimens ranging up to 25 mm in length.

Samples of silt were taken from the top of the crib and found to contain the following diatomaceous growth: *Melosira* sp., *Fragilaria crotonensis*, *Tabellaria fenestrata*, *Navicula* sp., *Cymbella* sp., *Cyclotella* sp., *Stephanodiscus minutus* and small quantities of *Scenedesmus quadricauda* and *Scenedesmus dimorphus* (green algae).

In general, algae and periphyton growth on the structure appeared to be more limited in the vertical plane than in the horizontal plane.

* * * * *

Date	21 September 1973	Dive No. 9
Location	South discharge structure	
Depth	20-30 ft.	
Team	John Dorr, Susan Williams	
Time	1320-1425 hrs. (65 min.)	

Observations

Horizontal visibility at working depth was 3 ft. Temperature was a constant

13.5°C. No noticeable current.

The bottom consisted of riprap with diameters ranging from several inches to three feet. Most of the riprap was silt covered and appeared to have remained undisturbed for possibly several weeks. Several 3-4 ft² areas of scour cloth were exposed in the vicinity of the structure. The orientation of these exposed areas in relation to the structures was not determined.

Several isolated pockets of organic debris were seen, but no rooted macrophytes were observed.

One transect 2 m wide and 30 m long was swum between the north and south discharge structures. Counts for crayfish seen along the transect were to be made, however no crayfish were seen. The only organism observed during the entire dive was one snail (*Physa integra*). The low abundance of observable organisms may have been caused by heavy silting or other disturbances created from nearby operations laying scour cloth.

Samples of the riprap in the area of the transect swim were retained for laboratory examination. They were found to be covered with a light growth of *Cladophora*, which in turn supported a periphyton growth composed primarily of *Cocconeis* sp., *Gomphonema* sp. and *Synedra* sp. A hydra colony was found growing on one of the samples of riprap.

* * * * *

Date	21 September 1973	Dive No. 10
Location	North control station	
Depth	22 ft.	
Team	John Dorr, Susan Williams	
Time	1630-1700 hrs. (30 min.)	

Observations

Horizontal visibility at working depth was 5 ft. Temperature was a constant 13.5°C. No noticeable current.

The station begins opposite the north range pole halfway between the intake and discharge structures, and proceeds north along the bottom.

Observed strongly developed symmetric ripple marks running from the northwest. Ripple marks measured 7 inches high and 24 inches crest-to-crest. Troughs were cut at 90 angle by fine ripple marks coming from the southwest. Heavy northwest swells had been coming in for a period of several days prior to this dive. The morning of this dive there had been a wind shift, and a light chop was coming from the southwest. Observed ripple marks were most likely generated as a result of these surface conditions.

Crests of the large ripple marks consisted of light colored, well sorted sand. Troughs consisted of darker finer sediment, not as well sorted, and containing some pebbles, bits of organic debris and snail shells.

One johnny darter was observed. Several empty shells of an aquatic snail (*Gonioabasis* sp. or *Pleurocera* sp.) were collected, along with several empty fingernail clam (*Sphaeriidae*) shells. No live molluscs were observed.

Area surveyed was free of debris and appeared to be biologically barren.

* * * * *

Date	21 September 1973	Dive No. 11
Location	South control station	
Depth	22 ft	
Team	John Dorr, Susan Williams	
Time	1715-1730 hrs. (15 min.)	

Horizontal visibility at working depth was 5 ft. Temperature was a constant 13.5°C. No noticeable current.

The station begins opposite the south range pole halfway between the intake and discharge structures, and proceeds south along the bottom.

Strong ripple mark development observed at the north control station was not evident at this location. Some asymmetric weakly developed ripple marks running from the west were observed. The riprap may have prevented ripple mark formation from the northwest, by disrupting the effect of the currents on the bottom.

No fish, molluscs, other invertebrates or fauna of any type (living or dead) were observed. Bottom was very clean, with little or no debris encountered.

SUMMARY OF OBSERVATIONS, 1973

1. The following species of fish have been observed by divers in the vicinity of the Cook Plant:

Intake structures	-	Spottail shiner Alewife Yellow perch Trout-perch Sculpin (possibly mottled and/or slimy) Johnny darter
Discharge structures	-	Yellow perch Sculpin (possibly mottled and/or slimy) Johnny darter
Control stations	-	Johnny darter

2. Snails were observed at intake and discharge structures (*Physa integra*) and at the north control station (empty shells of *Gonioabasis* sp. or *Pleurocera* sp.). Crayfish were seen only at intake structures. Fingernail clams (empty shells) were observed only at the control stations (sand or silt bottom).
3. Rooted macrophytes were not observed on any occasion.
4. *Cladophora* was observed to be growing on all structures examined. The density with which it grew varied, with the most luxuriant growth on the horizontal surfaces facing upward and directly exposed to sunlight.
5. Periphyton grew in varying densities on the surfaces of all objects examined. Samples included: *Cladophora* sp. (attached filamentous green algae); *Cymbella* sp., *Gomphonema* sp. and *Cocconeis* sp. (attached diatom); *Melosira* sp., *Fragilaria crotonensis* and *Tabellaria fenestrata* (planktonic diatom); *Navicula* sp. and *Synedra* sp. (attached or planktonic); *Cyclotella* sp. and *Sephanodiscus minutus* (planktonic diatom); *Scenedesmus quadricauda* and *S. dimorphus* (colonial planktonic green algae).
6. Dredging, riprap dumping and other construction activity immediately decreased faunal abundance and diversity. This decrease in abundance and diversity was probably caused by the turbidity and habitat disruption created during construction operations. Most likely, there is a stabilization interval between the end of habitat disruption and the establishment of an initial stage of ecological succession. The time length of this interval is not known, however, it may not be more than 1-4 weeks during the warmer months.
7. The discharge area had consistently lower levels of faunal abundance and diversity. This may have been the result of more frequent construction in this area.
8. Biological activity and diversity was higher on the one night dive than on any day dive.

9. The control areas (north and south control stations, Warren Dunes) were more biologically barren than the riprap areas in terms of numbers of observed fish, macrobenthos, algae and organic debris.
10. The riprap area appeared to disrupt ripple mark-forming water currents in areas immediately adjacent to the riprap area (i.e. the side downward from the direction of ripple mark formation).

1974 PROGRAM

Problems affecting the 1973 diving operations were primarily related to the limited scope of operations and adverse environmental conditions. The 1974 diving program has been expanded to include additional divers, more flexible equipment and a standard set of monthly observational dives. These monthly dives (April-November) will include day and night observations, and dives in the areas of the intake and discharge structures and at the control stations. Five to six dives per month are scheduled. Observations will include:

1. Day-night differences in faunal diversity, abundance and activity.
2. Comparison of the faunal diversity, abundance and activity in the areas of the intake structures, discharge structures and control stations.
3. Observations for:
 - Fish, fish eggs, fish larvae
 - Crayfish, molluscs and other macrobenthos
 - Rooted macrophytes
 - Algae, periphyton
 - Debris and decaying organic material
 - Scour indications in the area of the discharge structures
4. General visual analysis of the biological status of the area near the Cook Plant, and supplemental sampling operations.

